Fundamental Thoughts

of

Fundamental Physics

Dongsheng Wang

September 22, 2010

Contents

Abbreviations

AMO: atom, molecule, and optics.
ARM: Absoluteness and Relativity of Motion.
AST: absolute view of space and time.
BEC: Bose-Einstein condensate.
BM: Bohm mechanics.
CHI: consistent history interpretation.
CI: Copenhagen interpretation.
EI: existential interpretation.
GR: general relativity.
HVT: hidden variable theory.
LCI: the law of conservation of information.
LT: Lorenze transformation.
MWI: many worlds interpretation.
PCT: physical collapse theory.
QFT: quantum field theory.
QIQC: quantum information and quantum computation.
QM: quantum mechanics.
SPDC: spontaneous parametric down-conversion.
SR: special relativity.
TD: thermodynamics.
TI: transactional interpretation.

Acknowledgements

Abstract

What are the basic attributes of motion? What is the problem of the absolute view of space and time? What is the essence of the arrow of time? What is the essence of Quantum Mechanics? What is the essence of Relativity? What is the relationship between Quantum Mechanics and Relativity? What is the relation between Quantum and Classical? What is the mystery of Aether? What is the unified theory of Physics and Nature? For these fundamental questions, in these essays, I present interpretations different with the common ones. Generally, the problems of time in Physics are criticized, the Quantum Mechanics and Relativity are re-interpreted, the Nonlocality and Entanglement are studied, etc.. Further, we construct the new concepts *scope*, *yiang*, *anti-time*, *photocule* etc. and explore the unknown physics.

Chapter 1

The Concept of Motion in Physics

1.1 Introduction

.

In the first chapter, we mainly focus on the concepts of *motion*, *space*, and *time*. For a long time in the history, many thinkers explored these basic problems such as “Is the universe movable?”, “Are there basic elements of the universe?”, or “Is the basic element movable?”, etc.. In the Ancient Greek, the philosopher Parmenides believed that the universe is not movable, while it is compact, like an “iron plate”. However, the philosopher Heraclitus believed that the universe is movable, who said many adages, such as, the sun is new every day, and people can not step into the same river twice. Pythagoras found the mystery of *number*, and believed that the universe moves under the law of number [1]. As the civilization developed, mainly three means of cognition have been established in the west which are *philosophy*, *mathematics*, and *physics*, generally.

Philosophy, which is the most fundamental mean to study the universe and nature, focuses on the issue of *the essence of subject*, including the basic elements, the motility, and the properties of motion and so on. Based on the method of *critics* of philosophy, we can reach the essence of the substance from *sensuousness* to *logos*, going beyond the presentation which means the raw materials of the external and internal world. This mean of cognation is distinct from mathematics and physics both of which almost focus on the presentation. As the philosopher Aristoteles stated that “philosophy is meta-physics” [2], in the modern time we view philosophy as “the Science of Science”. Thus, when mathematicians and physicists surpass the limitation of themselves, it means that they are on the way to philosophy.

The foundation of mathematics is the concept of *number*, which can be either “the number of substance” or “the number of motion”, but not both of them, the reason is that the concept of number separates substance and its motion from each other. And the basic method of mathematics is *quantization* which splits the inseparable *quality*, thus, the motion of substance is reduced to "the law of number". This reduction leads to the profound outcome: *time* is broken, which sets the confliction between philosophy and mathematics. As the famous Philosopher Bergson says, time is *duration* [3], which means that time is inseparable, a kind of "continuum". As we all know, the "Continuum Hypothesis" is a fundamental mystery in modern mathematics. What is more, as mathematics deals with number and its structure, another key concept is *space*. Before the discovery of the imaginary unit i, time and space are viewed as *priori forms of intuition* [4], which can not be defined. While, the imaginary unit connects number and space together. Specially, multiplying i means "rotation", which serves as the origin of *direction*. Thus, the mathematics is based on the concept of *number* directly. The branches of modern mathematics such as fractal and topology are all based on this connection. The method of *quantization* lays the foundation of the whole science, forming a different tradition from philosophy. However, it can only enrich rather than substitute philosophy.

Physics, including all the other science based on it, lays its foundation on *the reality of substance*. Physics studies the motion instead of the subject itself, thus we can not classify physics according to the observed subjects, on the contrary, we should refer to the property of motion. The special method of physics is *experiment*, which connects experience and mathematics, thus combines the critics of philosophy and the quantization of mathematics. However, the contradiction between philosophy and mathematics induces a critical problem: the confusion of the concept of *time* in physics. For example, in different branches such as Mechanics, Thermodynamics, and the Field Theory, time have various meanings. The problem of time is one of the focus in our study below. It is reasonable to view physics as the most *effective* mean of cognation, thus its fundamental conceptual framework should always be criticized and corrected.

1.2 The Methods of Physics

.

In order to describes various movements, Physics employs different methods, and sometimes even employ many methods to describes the same movement due to some reasons, such as the difference of the subjects investigated, the mathematical skills and the historical effects. Generally, there are two ways to understand the methods of physics, one is according to the subjects we study, the other is according to the descriptions we use. Nowadays, as we all know, the branches of physics are Mechanics, Thermodynamics, Electromagnetics, Optics, AMO, Atom physics, Field theory, the Condensed Matter physics, and the Cosmology, etc.. However, as we have pointed out above, physics should better not be classified according to the subjects investigated. Here, from the view of description of motion, we try some new interpretation below.

As a general rule, we distinguish four kinds of methods: mechanics, thermodynamics, field theory, and systematics.

(1) Newtonian mechanics, or generally the classical mechanics (CM), is based on the concept of *force*, which is the cause of the change of movement. The movability of an object is replaced by *inertia*. Force has three factors: magnitude, direction, and the point of action. Motion can be synthesized and analyzed, which is consistent with geometry. Thus, force can also be synthesized and analyzed under the rule of geometry, *the parallelogram rule*. The movement of object satisfies the dynamics "the equation of motion + initial condition". At any time, there is one velocity $\mathbf{v}=\frac{d\mathbf{r}}{dt}$. In the Newton function $\mathbf{F} = m\mathbf{a}$, movement is reversible since the derivation of time is second order. Time is an absolute outside measurement, and it does not matter to timing at what time. In fact, there is no time in the motion. If we set the frame on the object itself, it should feel static itself.[1] In Mechanics, there are two kinds of forces: ordinary force and the force at a distance. As the speed of light is proved to be finite in electromagnetics and used to explain the gravity, the effect of motion on itself becomes obvious, this induces the discovery of *Relativity* especially the concept of *intrinsic time*.[2] However, in the theory of relativity, time is also spatialized. In the form $ds^2 = dx^2 + dy^2 + dz^2 - c^2t^2$, t is the form of square, thus the movement is reversible, which is similar with the Newtonian mechanics. This property of *the absence of time* is related to the methods and subjects investigated. In CM, only one subject is studied, such as a particle or a system of particles, the measuring time is external. Also the force is external. The inner state and the relation between itself and the outside are not considered. The *velocity* is another crucial concept which associates with time and space especially in the theory of relativity. The definition of velocity is based on the *relativity* of motion. However, it is hard to define the velocity in Quantum mechanics, which is related to its special form. In all, classical mechanics, including the Newtonian mechanics and the Relativity, describes the single casual dynamics.

(2) The research of thermodynamics (TD) begins mainly from gas, and then enlarges to all kinds of phases and smaller scales. This method is based on the concepts of *energy* and *temperature*, and related *entropy*, *enthalpy*, *free energy* and so on. *Energy* is one property of motion, neither the cause nor the result of motion, which can be transformed and transmitted under several rules, such as *the variation principle, the conservation law*, and *the equipartition theorem*. There are three fundamental principles: the principle of energy conversation and transformation, the principle of entropy increase, and the principle of inaccessibility of the absolute zero. Meanwhile, the Atom physics provides the microscopic basis of TD. The *temperature* is a scalar and a statistical value, which illustrates that TD studies the "collective" movements of a mount of objects instead of a single

[1] As a consequence, the Zeno's statement about the flying arrow is indeed right.

[2] Actually, the intrinsic property of time has been recognized in biology and psychology for quite a long time.

or few objects. It studies not only the whole external state, also the inner state such as the transition of energy, the fluctuation of the number of particles. Thus, *entropy* is very essential since it represents the time property of the motion, which is a basic difference between TD and CM. Besides, *the arrow of time* is mainly studied within TD. In all, thermodynamics describes the collective motion of an ensemble with internal and external states and the direction of time.

(3) The Field theory, exactly the quantum field theory (QFT), has been developed for a long time, from Faraday to Maxwell, Lorentz, and to Weyl, Einstein, and till the elementary particle physics. The subject studied is *field*, which can be excited into the elementary particles. Generally, the pattern of the motion of field is "kinematics + boundary condition", which is different from mechanics. And it uses the method of "energy" rather than "force". Due to its shapeless, such as the light field, the movement is "compound", and often only the states within the boundary are concerned. That is to say, the movement of field is "intrinsic", it moves by itself. Under the condition of a closed system, the movement is "no-time", which is similar with CM, while QFT describes a big compound motion, and CM describes a small single motion.

(4) Systematics describes a few amount of subjects and their movements, such as Quantum mechanics (QM) and the Nonlinear dynamics. There are definite mathematical skills of this method such as the *matrix equation* and the *system of partial differential equations*. The reason that we view QM as a kind of systematics is that it essentially and mainly studies a few amount of subjects and their movements, such as the entangled photons, strong correlated electrons, and the structure of atom, instead of a single subject or a compound subject or others. The basic concept of QM is *state*, every subject has one real state.[3] We can obtain the structure of movement by solving the equation of the state, namely, the Schrödinger equation. Compared with the method of "force", the method of "energy" is more suitable. In addition, the concept of *state* has been generalized into the research of QFT, and it could be also used in other studies.[4] In the nonlinear dynamics, multiple modes of movements interact together, such as the *synergy* and *feedback*, forming an *astable open system*. The essential trait of systematics is the *multi-subjectivity* of movement. Thus the structure of space and time is multi-level and multi-scale. There are both internal and external causes. Both the methods of "force" and "energy" are proper due to the *complexity*. In addition, we should better notice that systematics is a quite new discipline and description, lots of subjects such as the entangled states and chaos are still developing far from completion.

What is more, we have to discuss a little more about the methods of *force* and *energy*. Often they work together without confliction, and the mathematical transformation between them is quite simple. However, there are several differences

[3] Indeed, in Chapter 2 and follows, we will develop a new interpretation of QM.

[4] About a new kind of interpretation of Quantum mechanics, please read Chapter 3.

fundamentally. *Force* is the cause to "change" the motion, while the movability is called *inertia*. The method of force is based on *casuality* which means that everything has a cause including external and internal. For example, the essence of Relativity is casuality. Force has the property of *causality* and *separability* which includes *synthesis* and *analyse*, thus the explanation of force is *dynamical* and *intuitive*. At the same time, *energy* is viewed as the property of motion, neither the cause nor the result. Thus, the method of energy is a kind of "description" instead of "explanation". Energy has the property of *conservation, transformation*,[5] and *transmission*. The description of energy is *kinematic* and *abstract*.

In addition, in the above study, we do not relate to the scale of the subjects investigated, such as microscopic and macroscopic subjects. We should demonstrate again that the methods of description of motion are independent of the substance. For instance, "force" can be applied in single macroscopic movement as well as microscopic movement, the same with the thermodynamics. At present, the systematics still needs lots of exploration. However, the traditional view of Quantum mechanics holds that it can only be applied in the microscopic world, which conflicts with the standpoint of this work.

1.3 Space-Time and Motion

.

In this section, we focus on the relation between *motion* and *space-time* below, and we do not intend to study the origin of the concepts of time, space, and motion in detail. One of the basic problem is: Can time and space exist independent of substance?

In the ancient, *time* and *space* are not explored together though, it is mainly in modern time that they were studied with each other. In the Ancient Greek, the "atomism" of Leucippus and Democritus stated that the space (or the vacuum) is subject itself. *Vacuum* and *atom* are the two basic elements of substance, the former one has no definite form, and the latter one can not be divided. However, they encountered some troubles such as "Can the space or vacuum be occupied?" [1]. In order to solve it, philosophers afterwards viewed the space as a kind of "framework", which is the beginning of *the absolute view of space and time* (AST). In the modern time, Descartes used the concept of *extension* to describe both the subject and the space, thus space is viewed as a kind of subject [5]. While, different from *space*, the development of *time* is related to motion. Heraclitus believed that everything is inconstant, while others such as Parmenides and Plato denied the reality of motion and time. It is Newton who established the AST, where time and space are beyond motion. Space is absolute and uniform, time is absolute and inconstant. Everything has a *place* in time and space [6]. Newtonian Mechanics

[5] No matter the interaction is electromagnetic or gravity, the energy is universal

makes the motion simple and easy to be described by mathematics, however, it results in the *spatialization* of time and even the *absence* of time from motion. For example, in *the law of gravity* there is no time, so the gravity seams like the "action at a distance". This simplification is quite effective to the mechanical motion. However, the AST never govern in biology. The concept of *biological clock* is directly connected with every life form. As a result, when physics intends to cope with some complex behavior and motion, problems arise. Actually, the AST never obtain the dominance in history, while on the contrary, there were always opponents. Leibniz who was the same time with Newton was against this absolute view, and he argued that motion is impossible in the uniformed space-time using his famous *principle of sufficient reason* [7]. Time and space are directly connected with motion, and also time has different structures such as linear and circular. Also, for example, the philosopher Berkeley held the same standpoint with Leibniz.

From above, we know that although the AST has existed for a long time, while the intrinsic logic is not self-consistent. It faced an arduous paradox: Is space-time finite or infinite? This is also the first *antinomy* of Kant, who stated that this paradox could not be solved [4]. After that, Hegel found that antinomy is the universal manner of substance [8], thus the paradox is a "false" problem. We state that the reason for this paradox is due to viewing space and time as subject rather than the *attributes* of motion. In principle, one subject can not be occupied by another subject. From Hegel on, materialists such as Engels held that *space* and *time* are the primary attributes of motion, both of them can not exist independent of substance, time describes *continuity*, and space describes *extensivity* [9]. This is the solution of the problem of the AST in philosophy. At the same time, modern science has improved a lot and transformed the view of time and space. *Relativity* connects time and space together, also the motion of particles and fields. What is more, the *General Theory of Relativity* introduced new ideas such as the extend, retract, and bend of space-time. However, it has not reached an unification of philosophy and physics, we do not intend to study this issue here.[6]

On the concept of *motion* there also exist contradictions, which is mainly due to the confusion of the "basic elements" of the universe and the relation between motion and space-time. For instance, based on different basic element, such as water or gas, philosophers often reached different answers. The more fundamental contradiction is due to their different standpoints, including philosophy, mathematics, and physics. For instance, the standpoint of Parmenides is philosophy, he believed that the universe is permanent thus it is also unmovable. On the contrary, physics studies the motion of the substance, thus *movability* is its "precondition". Philosophy and physics care different characters using different ways, thus there is no "antinomy" between them. Further, on the property of motion, there is the notable paradox in the Ancient Greek called the "paradoxes of Zeno" [1], one of

[6] We will study the problems with the theory of relativity in Chapter 6 and 7 in detail.

which states that the flying arrow is not movable as it can not leave itself. This paradox relates to the property of the *absoluteness* and *relativity* of motion. Another paradox states that Achileus can not catch up with one tortoise which starts running earlier. This paradox relates to the property of the *finiteness* of motion and has been resolved by the theory of *limitation* in mathematics.

Not only the understanding of motion, also the understanding of the structure of substance, such as the *field*, have been developed. The Field theory states that, field is a kind of subject full of the universe, the *elementary particles* are the excitation of field, and the motion of the field represents the motion of the universe. Time and space are the description of the motion instead of as its framework and cause. We believe that the Field theory provides a self-consistent explanation for the problems of motion and basic elements (however, this is only partly true). Based on this, we can set up a "logic diagram" of motion instead of based on time and space, which is shown as follows:

$$\begin{array}{ccccc} fields & \longrightarrow & interactions & \longrightarrow & energy \\ \Updownarrow & & & & \downarrow \\ motion & \longleftarrow & form, phase & \longleftarrow & forms\ of\ energy \end{array}$$

In the diagram, the arrow represents *cause* (such as $i \to j$ means i is the cause of j). Various fields and elementary particles induce different kinds of symmetry and interactions. The interaction connects with the properties of energy including *conservation, transformation*, and *transmission*. Energy has kinds of forms such as electric energy, thermal energy, and nuclear energy. Then the motion of energy produces many objects such as water, stone, and distinct phases such as liquid, solid, and plasma. And last due to the difference on forms and phases, all kinds of objects lead to motion, which is at the beginning of the logic diagram, thus forming a "cyclic". The *motion* connects with the *substance* itself directly. The reason is intuitionistic. Suppose there only exists one basic element, such as *photon*, then can the object move? Obviously, under this condition, motion is meaningless. In addition, time and space can be used to describe the motion, however, the definition and cause of motion can only be decided by the substance itself.

Further, another central problem is, how *time* and *space* are used to describe motion? We cite the famous definition of Aristoteles in his classical work *Physics* [10]. In this book, he studied the concepts of time, space, motion, place, etc.. He defined *time* as "the number of motion", so different movements have different times. Also every object has a *place* in the space, which is not the same with the AST of Descartes and Newton. If we absolutize time and space as quantized background, then we get the AST. We demonstrate that time and space should not be viewed as independent of substance and its motion, if not, there will be lots of paradoxes. It is natural and beautiful to view them as the attributes of motion, that is, time describes *continuity*, and space describes *extensivity*.

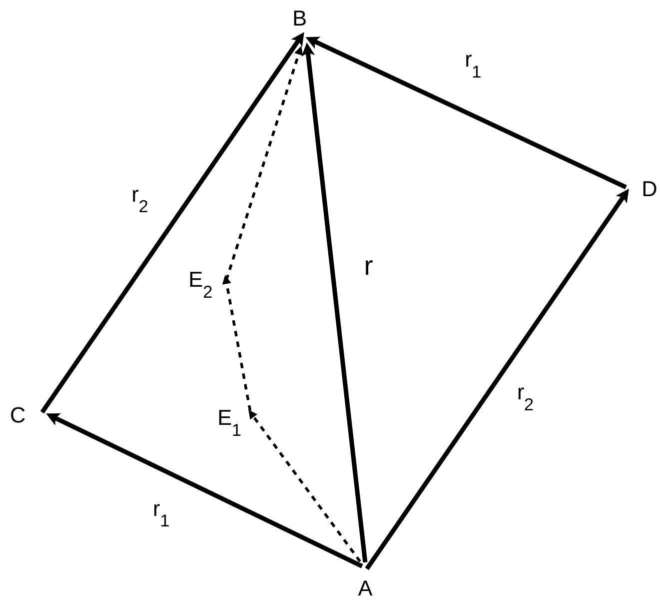


Figure 1.1: The attributes of motion.

.

1.4 The Attributes of Motion

.

From the study above, we prove that time and space are the two fundamental attributes of motion of substance, and they have different physical meanings. Now, if we ask the questions: Are time and space the only two attributes of motion? Is the description of time and space of motion complete? Anything beyond time and space? Physics can not answer, neither Mathematics, while Philosophy can only give some hints. No one can give definite answer. Their is no time in Mathematics, there is confusion of time in Physics, and there is mystery of time in Philosophy. Next, let us analyze an example in order to find something more.

In Figure 1.1, we want to describe the movement from A to B. First, we have to choose some certain space to define the variable. Here we chose the coordinate frame without losing of generality. There are three simplest ways to finish the motion, listed as follows:

a: from A to B by $\mathbf{r}$*;*
b: from A to C then to B by $\mathbf{r_1} + \mathbf{r_2}$*;*
c: from A to D then to B by $\mathbf{r_2} + \mathbf{r_1}$.

Geometrically, $\mathbf{r} = \mathbf{r_1} + \mathbf{r_2} = \mathbf{r_2} + \mathbf{r_1}$. If $\mathbf{r}$ represents more general transformation, such as rotation, then $\mathbf{r_1} + \mathbf{r_2} \neq \mathbf{r_2} + \mathbf{r_1}$.

While physically, these three movements are different definitely, at least, they have various paths. Thus,

$$(a) : \mathbf{r} \neq \mathbf{r_1} + \mathbf{r_2}, \qquad (1.1)$$
$$(b) : \mathbf{r_1} + \mathbf{r_2} \neq \mathbf{r_2} + \mathbf{r_1}.$$

What we could state is that Physics is different from Geometry. The relation (a) indicates that one certain movement cannot be divided, instead, it is inseparable and integral. The relation (b) indicates that one movement has some unique structure, which relates to the extensivity of the movement. At the same time, the direction of movement indicates the continuity of the durable movement. That is to say, the difference between Physics and Geometry indicates the attributes of motion. Obviously, the thing that describes *continuity* is time, the thing that describes *extensivity* is space, and the thing that describes *integrity* is something else, which we name as "yiang".[7] In addition, in Figure 1.1, there is also another path $A \rightarrow E_1 \rightarrow E_2 \rightarrow B$, this complex movement, also some other even more complex movements, have the same fundamental attributes. So, we find something more.

Interestingly, the three attributes have wonderful properties and relations among them. The properties of them are shown in Table 1.1, and the relations among them are shown in Figure 1.2. We use λ to stand for yiang, and in the table, D stands for dimension.

Table 1.1: The three attributes of motion.

t:	continuity	generative	scalar	1-D	$t_1, t_2, t_3...$
r:	extensivity	extended	vector	3-D	$\mathbf{r_1} + \mathbf{r_2}$
λ:	integrity	relational	spinor	2-D	$\begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix} \neq \begin{pmatrix} \lambda_1 + \lambda_2 \\ 0 \end{pmatrix}$

Time is generative, is one dimensional scalar, can be written in the extensive form of space, as $t_1, t_2, t_3, ...$ Time is easy to be spatialized, and time relates to space by velocity $\mathbf{v} = \frac{d\mathbf{r}}{dt}$.

Space is extended, is three dimensional vector, can be written in the relational form of yiang, as $\mathbf{r_1} + \mathbf{r_2}$, where $\mathbf{r_1}$ and $\mathbf{r_2}$ are inseparable. Space and transformations can be expressed as matrix.

[7]Here we introduce "yiang" from this simple example. Actually, this attribute of motion has its fundamental origin in the scientific methods of ancient Chinese culture. In Chinese, it is named as "易间". However, I have not yet found any word that can express the proper meaning in English, so I have to make up the new word to symbolize it at present.

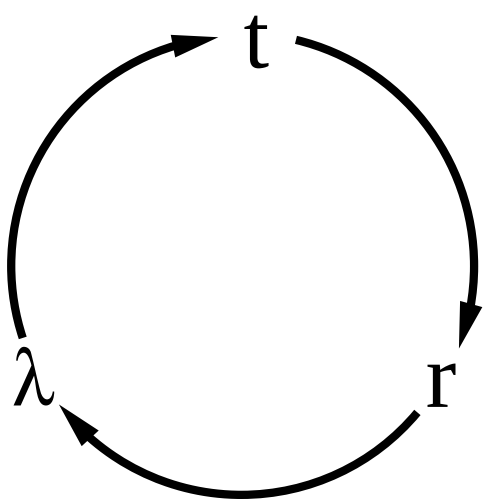


Figure 1.2: The relations between time, space, and yiang.

Yiang is relational, is two dimensional spinor,[8] can be written in the evolutive form of time, as $\begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix} \neq \begin{pmatrix} \lambda_1 + \lambda_2 \\ 0 \end{pmatrix}$. Yiang can be scalarized by the reduction from algebra to number.

The introduction of "yiang" completes the description of motion. We need at least three attributes to describe a movement completely. In the example above Equation 6.1, the relation (a) $\mathbf{r} \neq \mathbf{r_1} + \mathbf{r_2}$ means $\begin{pmatrix} \lambda \\ 0 \end{pmatrix} \neq \begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix}$. This form looks like something in QM. In fact, in Chapter 5, we will show in detail that the foundations of QM and Relativity connect with the concept of yiang on a fundamental level.

1.5 The Properties of Motion

.

Associated with the three basic attributes of motion, there are several properties of motion as follows.

1. *Integrity*. Motion is integral, unique, and conserved. This property is determined by substance itself, as substance is integral,[9] unique (object differs from each other), and conserved (energy can not by created or demolished). Substance and its motion both have the property of integrity.

Below we briefly talk about some applications.

[8]The reason that spinor is chosen to describe yiang is that the spinor has two components. Here we do not relate to the field theory. Also, it is natural to use matrix to describe the integrity of motion.

[9]For example, the separation of electrons from nuclear can destroy the structure of atom.

(1) Information is a form of motion, it is integral, unique, and conserved. While this statement is conflict with the common idea directly. In fact, information can "multiply" rather than "duplicate" itself, by each multiplication some difference is added. The *quantum non-cloning theorem* just demonstrates this property [11]. We will discuss information in detail in the following chapters.

(2) The synthesis and analyse of motion. Often the total effects of several movements is the same with effect of one single movement, however, it does not mean that all the effects are the same. For instance, when one squeezes the sponge from two sides, although the *resultant force* is zero, the sponge is squeezed, which is different from the effect when there is no force on the sponge. Generally, Newtonian mechanics studies the *casuality* of motion while ignoring the *integrity*, thus, the synthesis and analyse of motion can be only applied within a quite limited scope.

(3) The entangled state, which is also the foundation of the Quantum information, is an integral subject. For example, the photon pairs generated with the method of SPDC (spontaneous parametric down-conversion) can not be viewed as two systems. When one part, that is the inner part, of it is measured, the state could be destroyed.[10]

2. *Absoluteness* and *Relativity*. First we should notice that here the property does not mean that of time and space, but of motion itself. Take the famous "bucket experiment" of Newton for example. Newton supposed that when the bucket starts to rotate full of water, the surface of water would become concave. In this process, the relative motion of water to bucket decreases, while the absolute motion of water increases. The magnitude of centrifugal force means the absoluteness of the motion [6]. While, Mach afterwards opposed the absolute motion. Mach stated that when the bucket is fixed while the water is rotating, the water should be acted by the centrifugal force and form a concave surface. But the water moves relative to the bucket, thus the motion of water is not absolute, and the magnitude of centrifugal force can not mean the absoluteness of the motion [12]. After that, Poincare and Einstein gave this problem a new understanding with the theory of Relativity. *Absoluteness* means the ability of motion relative to *ether*, which can not be defined by the reference frame, mind or other motion. In addition, we can provide the proof of absoluteness based on the logic diagram in the section 1.2, which states that the movability is determined by the elements of substance. While, when one movement is compared with another movement, a relative relation exists between them. In physics, most of the time we study the relative movements. However, we should bear in mind that the relativity is based on and connected with the absoluteness.[11]

3. *Symmetry*.

(1) Relativistic invariance.

[10] We can view this kind of measurement as incomplete. The measurement problem of QM is beyond this work.

[11] For a further study on this issue, please read Chapter 6.

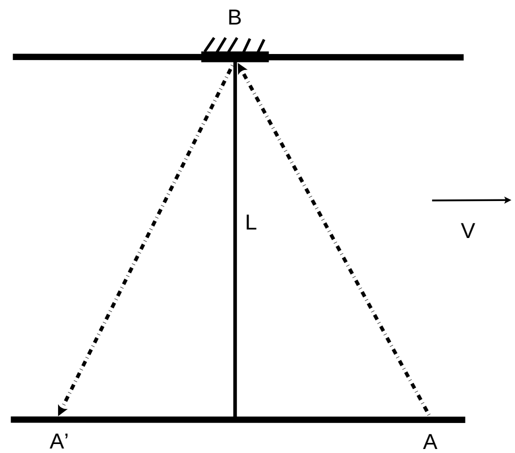


Figure 1.3: Relativistic invariance. The system moves with a speed of $\mathbf{v}$, the observer sees that the light goes from A to B, then to A'. The vertical displacement is L.

Strictly speaking, all the movements of objects are relativistic. According to the elementary particle physics, there are two kinds of matter: particle and field, the motion of which can be connected using the Lorentz transformation (LT) in the Field theory. The Special Relativity (SR) presumes that the speed of light in vacuum is constant and independent of the light source. Thus, all the movements under the electromagnetic interaction have the limitation of speed of light. As velocity is the function of time and space, based on the concept of *motion*, we employ the electromagnetic field to "measure" the motion of matter, which can lead to a quite new understanding, we give an example below.

Since an object is always static relative to itself, we introduce the idea *intrinsic time* and *intrinsic space* to describe the motion. Figure 1.3 shows the relativistic movement we study. First, when we observe *in* the system, we get that the light goes from A to B then back to A. It satisfies $c = 2L/t$, where c is the speed of light, t is the time of light. It is natural to chose the "base time" τ and "base space" l satisfying $c = 2l/\tau$. Then we observe *out* of the system, when the system is static we certainly get the same outcome with the above case. But when it moves with $\mathbf{v}$, we get the path of light $A \to B \to A'$, and $(ct)^2 = L^2 + (vt)^2$, which is $t = \frac{L}{c\sqrt{1-v^2/c^2}}$. The time of light is $2t = \frac{2L}{c\sqrt{1-v^2/c^2}} \equiv t'$, thus, $c = \frac{2L}{t'\sqrt{1-v^2/c^2}}$. If we chose the "base time" and "base space" $\tau' = \tau\sqrt{1-v^2/c^2}, l' = l$, thus, $c = 2l'/\tau'$, which is the same with the former case.

comment on this part: the conclusion is right. Jun15, 2013
a vector in R3 is actually a ``path'', motion. The real vector in R is
just a point, e.g. O. The vector AB is a motion, by ``time reversal''
in common sense, here ``time'' is the intrinsic time (order) of the motion,
then reversal means the inverse of the motion. If the motion is a path
in R, then time reversal means local space reflection.
However, the problem is:
the ``time'' in physical equation is external;
so the correct time reversal for physical equation
is t to -t. Let us call it ``timing reversal''.

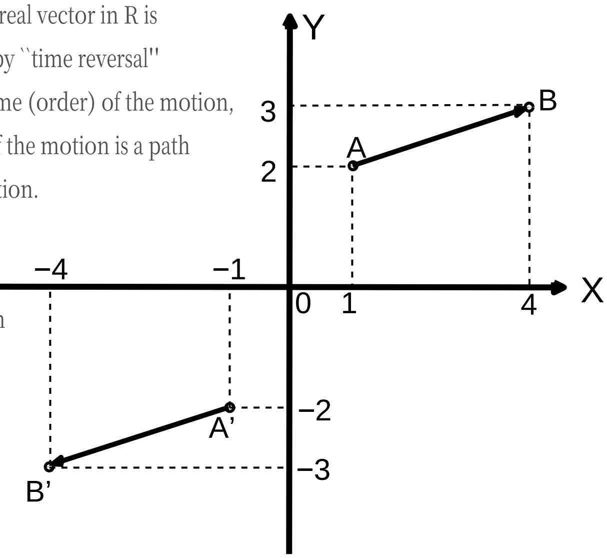


Figure 1.4: The properties of motion. $A \to B$ represents the movement.

From this brief example, we demonstrate that the relativistic effect arises as the result of the difference of "base time" and "base space". The relation between the system and the observer plays a central role, while the property of the system itself does not change.

In addition, in the General Relativity (GR) where the effects of mass and non-inertial movement are considered, light moves along the *geodesic*, and the structure of space-time should change. However, the change can only be observed relatively rather than by itself. In all, the theory of Relativity describes the property of movements mainly due to the *relation* rather than themselves.

(2) The symmetry of time and space.

Here we study the common symmetries including the *time reversal, time translation, space reflection, space translation*, and *space rotation*. As we usually isolate time and space from motion, there are some confusion of the basic methods, we try to show that below.

In Figure 1.4, we study the movement $A \to B$. Set up a 2-dimensional frame XOY, O is the origin. Given A(1,2), B(4,3), for instance, $A \to B$ labels as [(1,2),(4,3)] or $\overrightarrow{AB}$:

a. Space reflection. We apply the reflection about the origin O. A(1,2)$\to$ A'(-1,-2), B(4,3)$\to$ B'(-4,-3), the results are [(-1,-2),(-4,-3)] or [(-4,-3),(-1,-2)]. This uncertainty illustrates the space reflection is not enough to describe the transformation, we still need another symmetry. The reason is that it does not account

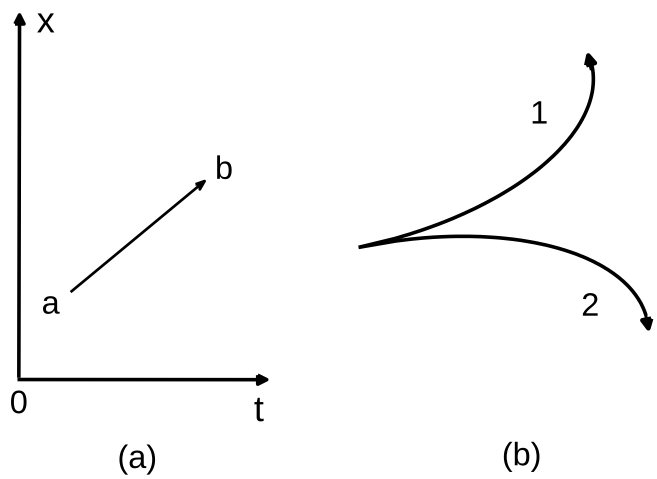


Figure 1.5: (a)The reversion of motion and the time inversion; (b)CPT theorem.

the issue of "the direction of motion", that is the problem of "time".

From Figure 1.5(a), in the frame tOx, the inversion of the motion $a \to b$ is $b \to a$, both as time reversal and space reflection. We should notice that here the "time reversal" is not the "real" reversion of time, in fact, it is the reflection of space, that is "the reversion of motion". We will further study the problem later.

Thus, we can define three kinds of transformations of space below:

Local space reflection: $P_{l(ocal)}$:$\overrightarrow{AB} \to \overrightarrow{BA}$ (the reversion of motion itself).

Global space reflection: $P_{g(lobal)}$:$\overrightarrow{AB} \to \overrightarrow{B'A'}$ (~~This is the so-called "space reflection" in text book, the place in the coordinate changes, while the motion itself remains~~). mirror reflection is combined space reflection.

Combined space reflection: $P_{c(ombined)}$:$\overrightarrow{AB} \to \overrightarrow{A'B'}$ (the combination of the local and the global space reflection).

b. Space translation. In Figure 1.4, if $\overrightarrow{AB}$ and $\overrightarrow{B'A'}$ are parallel, the reflection of $\overrightarrow{AB}{\to}\overrightarrow{B'A'}$ is indeed the space translation. That is to say, the space translation is a kind of global space reflection when the direction of motion relative to the coordinate remains.

c. Space rotation. Generally, if the rotation includes the "global space reflection", it is called "extrinsic rotation", if not, it is "intrinsic rotation". We do not intend to study this symmetry in detail.

A note about the CPT theorem: the transformation PT is actually P_c. From Figure 1.5(b), when the particle moves along the path *1*, thus, the *antiparticle* must moves along the path *2*, which forms the "mirror symmetry" with the path *1*.

d. Time translation. For the same movement, it does not matter to timing

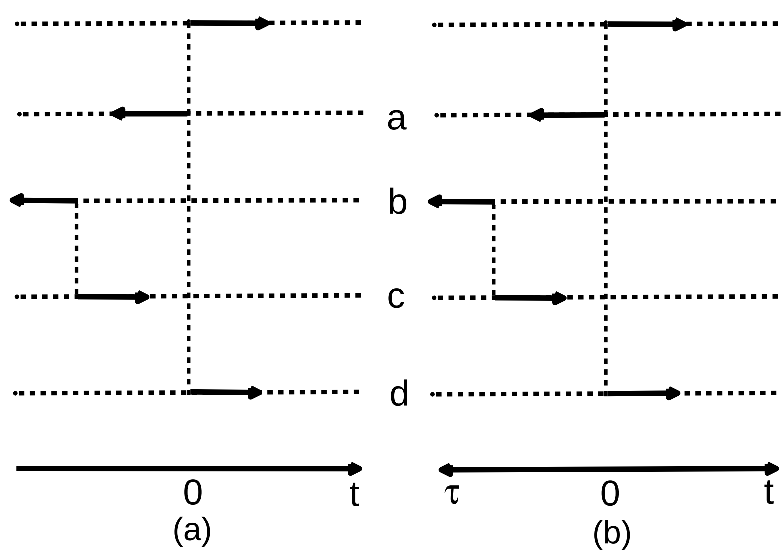


Figure 1.6: The time reversal.(a):The common reversal in text book. (b): The reversal defined in this work. t is the time, τ is the "anti-time".

at what moment since the energy is conserved. If the velocity changes, the time translation will cause some effects, for instance, the momentum is not necessarily conserved.

e. Time reversal. This is on of the main focus of this section. Time is defined as the number of motion, it means "timing the motion". Thus, it is increasing: $t \in (0, \infty)$ or $t \in (-\infty, +\infty)$. Naturally, after reversal, the time should be decreasing, labels as $\tau \equiv -t$. We name τ as "anti-time". Next, we talk about the common interpretation of time reversal [13].

In Figure 1.6, consider four transformations of time, satisfying

$$\text{translation (d)} \cdot \text{reversal (c)} \cdot \text{translation (b)} \cdot \text{reversal (a)} = I.$$

The operator of time translation is $e^{-iHt/\hbar}$. For panel(a): $e^{-iHt/\hbar}T = Te^{iHt/\hbar}$, thus for the infinitesimal transformation: $e^{-iH\delta t/\hbar}T = Te^{H\delta t/\hbar}$, which is $(1 - iH\delta t/\hbar)T = T(1 + iH\delta t/\hbar)$, thus $iHT = -TiH$. If T is unitary operator, we get $HT = -TH$, and $HT\psi = -E(T\psi) \Rightarrow$no lower bound. This is not right, thus T should be anti-unitary operator, which is firstly defined by Wigner [13].

However, we interpret the time reversal as "the reversal of timing", not "the reversion of motion". Thus, after reversal, t becomes $\tau = -t$. The transformations are shown in Figure 1.6(b). Thus $e^{-iH\tau/\hbar}T = Te^{-iH\tau/\hbar}$. It is easy to get $iHT = TiH$, Obviously, T is unitary operator, and $[T, H] = 0$. This is in confliction with the common definition above.

We should demonstrate that the point is the common interpretation makes the time "spatialized", thus confuse the *time reversal* and the *space reflection*. Actually, the common "time reversal" is the "local space reflection" P_l, corresponding to two "i" transformations: $(i^2 = -1)$, P_l is the anti-unitary operator: $P_l iH = -iP_l H$.

In addition, the common interpretation of "statistics" and the "Kramers degeneracy" are both right, as long as we should change T into P_l.

f. Symmetry and conservation. First, under the space translation, the energy and momentum are both conserved since the absolute and relative directions of the movement both remain. Second, under the space rotation, the angular momentum is conserved, which means the 3-dimensional space is isotropic.

The *parity* P is associated with the global space reflection. Define $P_g|\mathbf{r}\rangle = |-\mathbf{r}\rangle$. From $P_g^2|\mathbf{r}\rangle = |\mathbf{r}\rangle$ we get $P_g^2 = I, P_g = \pm 1$, corresponding to the even and odd parity. There are three kinds of space reflections: the local P_l, the global P_g, and the combined P_c. It is natural to get $P_c = P_l P_g$, thus P_c is anti-unitary operator. Plus, there are no conserved quantity corresponding to P_c and P_l.

time reversal has a relation with spin.

Particularly, we can introduce a new conserved quantity corresponding to the time reversal, labels as T,[12] which is the counterpart of the *parity* P associated with the global space reflection. T satisfies $T^2 = 1$. $T = 1$ means even, and the motion is reversible; $T = -1$ means odd, and the motion is irreversible. In addition, when there is degeneracy, there is no definite parity P with the eigenstate of energy, either T. However, we can translate to the eigenstate of P and T through the linear transformation. For example, the 1-dimensional free particle $\psi(r,t) = e^{-ikr}e^{i\omega t}\psi(0)$, as $[P, \mathbf{P}] = 0, [T, H] = 0$, there is no definite P and T. Applying the superposition with $\psi^*(r,t) = e^{ikr}e^{-i\omega t}\psi^*(0)$, we get: $\frac{1}{2}(e^{ikr} + e^{-ikr}) = \cos kr$ (even P), $\frac{1}{2i}(e^{ikr} - e^{-ikr}) = \sin kr$ (odd P), $\frac{1}{2}(e^{i\omega t} + e^{-i\omega t}) = \cos \omega t$ (even T), $\frac{1}{2i}(e^{i\omega t} - e^{-i\omega t}) = \sin \omega t$ (odd T).

Application. For the Schrödinger Equation $i\hbar\frac{\partial\psi(r,t)}{\partial t} = H\psi(r,t)$, apply T: $i\hbar\frac{\partial\psi(r,\tau)}{\partial\tau} = H\psi(r,\tau)$. The form of the equation remains.[13] Also, we can verify that the Newton Equation and the Hamilton Equation both satisfy the invariance of time reversal.

if H or F do not depend on time.

g. Relativistic invariance. Based on the study above, we could recognize the Lorentz transformation as the "measurement transformation of space-time", which means the change of the "base" time and space, such as extending, retracting, even bending. Under this transformation, the conserved quantity is the speed of light c.

[12] Unfortunately, I have not found a proper name for T as the counterpart of parity.

[13] As a result, the usual definition of time reversal in textbook is wrong. Actually, one can find that the definition in textbook is space reflection.

1.6 The Structure of Time

.

In this section, we briefly discuss another tough problem: *the arrow of time*. As we have demonstrated, the common strategy in physics is to spatialize time, such as the problem of time reversal and the theory of Relativity. In fact, when we deal with the simple movement of the simple system such as the movement of the mass point or the planet, the way of timing has no influence on the motion, thus, the influence is often neglected and the space-time is viewed as absolute. In the history, it is the classical thermodynamics that firstly brought up the problem of time, *the arrow of time*. Clausius found that the entropy of the universe increases to the maximum which means the "dead silence". As we know, the entropy is statistical, the harder the disorder, the bigger the entropy. The "time" with the arrow raised by the entropy is different from the "absolute time" we talked above. The entropy is quantized as $S = dQ/dT$, or $S = -\sum p_i \log p_i$, where p_i is the probability. In Quantum mechanics, the entropy is defined as $S = -Tr\rho \log \rho$, where ρ is the *density matrix*. The relation between entropy S and time t is that the *ensemble average* is equivalent with the *time average*, that is the *ergodicity*. As the time of the system itself can not be measured, we use the entropy to simulate it. What is more, as the physicist Schrödinger said, *life relies on negentropy*. When life grows, its "activity" increases while the entropy decreases, thus life becomes more and more ordered. So, the arrow of time does reflect the property of the whole motion rather than the property of the time, the "name" is a little misleading, it is better to say "the arrow of motion". Thus, it is more widely talked by philosophers and even psychologists. Further, the second brought up of time in physics is due to the theory of Relativity. It connects time and space and breaks *the absolute view of space and time*. However, it inherits the spatialization of time, and as it is not statistical, it does not raise the problem of the arrow of time.

Further, *the structure of time* has been investigated by philosophers, anthropologists, and biologists for a long time. In the ancient, people held a consciousness of the circular time, such as the motion of the sun, the moon, and even the life and death. While on the contrary, the *Darwinian evolutionism* set up the linear time, from simple to complex, from hydrophytic to terrestrial, and from lower to higher. Along with that, the concept of *progress* has been developing from the *Renaissance*. The great thinker Francis Bacon believed that the accumulation of knowledge formed the power of the progress of the society and human being. So, how can the confliction between the circular time and the linear time be interpreted? We hold that both of them are a part of the true time, the *helical time*, the linearity corresponds to the relation between the motion and the outside, while the circulation corresponds to the motion itself.

From Figure 1.7, the helical time t itself is inseparable, however, for the convenience of quantification, it can be projected to two parts: the linear part t_1 and

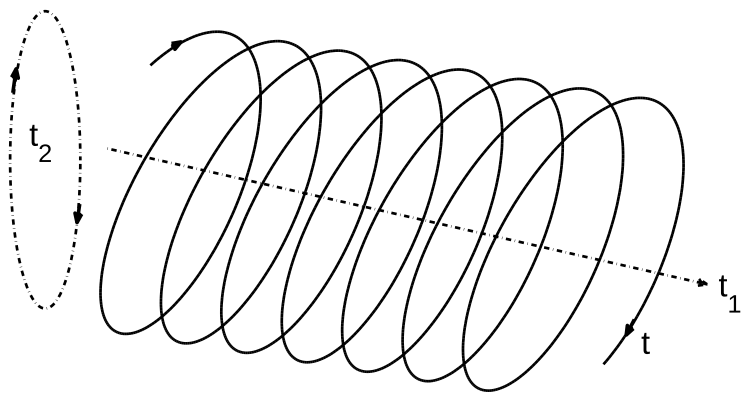


Figure 1.7: The helical time. t represents the time, t_1 and t_2 are the projected time. The arrow represents the direction of the increase of time.

the circular part t_2. The linear time is progressive and irreversible, the circular time is reversible, while the whole helical time t is irreversible.

Also we briefly discuss some applications below.

(1). The motion of the earth. The time of the *revolution* is t_1, and the time of the *autorotation* is t_2, which results in the *seasons*.

(2). The development of human being or other species. The time relative to the nature is t_1, and the time of itself is t_2.

(3). The growth of individual. The time relative to the society is t_1, and the path from child to adult to the old forms the time t_2.

What is more, there is one profound difference between the *inorganics* and the *organics*, that the former tends to be simple and steady while the latter tends to be complex and active. Recently, there have been critical development in the nonlinear dynamics, which is called by the famous scientist Prigogine as “the New Dialog between Human Being and Nature” [14]. The inorganics has little *movability*, which means the ability of motion, so the time in physics is often external, also we have seen that the entropy plays a more crucial role in biology than in physics. The organics especially human being has strong *movability*, both t_1 and t_2 are obvious. Based on this distinction, we demonstrate that the motion of inorganics and the organics are opposite, also *the arrow of nature* and *the arrow of life* are opposite.[14]

[14]Further study should go beyond this work, however. And, I have to apologize that all the cited books I have read are Chinese Version. For the English Version, I only read the parts cited in this work.

1.7 Conclusion and Introduction

.

This first chapter lays the primary mood of the whole work. We demonstrate that *physics* is a special means of cognition in which the concepts of *time, space* and *motion* are important. We distinguish four kinds of methods in physics which are the *mechanics, thermodynamics, field theory* and *systematics*. We should notice that they are connected although different from each other.

We state that time and space should be recognized as the basic attributes of motion, describing the *continuity* and *extensivity* separately, and they are not independent of motion, the *absolute view of space and time* is not proper. With the new concept *yiang*, our description of the attributes of motion becomes more complete.

Also, we discuss the properties of motion, such as the *integrity, absoluteness*, and *symmetry*, especially the properties of time and space. We give new interpretations of the *theory of Relativity*, *space reflection*, *time reversal*, *the arrow of time*, and the *helical time* from a more general view.

In the following chapters, we will discuss special issues, such as the foundation of Quantum mechanics, the unification of Quantum mechanics and Relativity. This will prove to be a long-drawn arduous journey yet with acquisition. So, please enjoy the way to the fundamental thoughts of fundamental physics.

Bibliography

[1] E. Zeller, *Outlines of the history of Greek philosophy* (Routledge, London, 2001).

[2] Aristotle, *Metaphysics* (Oxford, Clarendon Press, 2006).

[3] H. Bergson, *Time and free will* (Routledge, London, 2002).

[4] I. Kant, *Critique of Pure Reason* (China Social Sciences Pub. House, Beijing, 1999).

[5] B. Russell, *A history of western philosophy* (Simon and Schuster, New York, 1972).

[6] I. Newton, *Mathematical principles of natural philosophy* (Berkeley: Univ. of California Pr., 1999).

[7] G. W. Leibniz, *New essays concerning human understanding* (The Open Court Publishing Company, Chicago *etc.*, 1916).

[8] G. W. F. Hegel, *Hegel's Logic* (translated by William Wallace, Clarendon Press, Oxford, 1975).

[9] S. E. Stumpf and J. Fieser, *A history of philosophy* (Peking University Press, Beijing, 2006).

[10] Aristotle, *The complete works of Aristotle* (edited by Jonathan Barnes, Princeton, N.J. : Princeton University Press, 1984. 2006).

[11] W. K. Wootters and W. H. Zurek, Nature **299**, 802 (1982).

[12] E. Mach, *Knowledge and Error* (translated from the German by T. J. McCormack, D. Reidei Publishing Company, 1976).

[13] E. P. Wigner, *Group Theory and its Application to the Quantum Mechanics of Atomic Spectra*, chap. 26 (Academic Press, 1959).

[14] I. Prigogine and I. Stengers, *Order out of Chaos* (Bantam Books Inc., 1984).

Chapter 2

SCOPE

2.1 Motivation

.

In this chapter,we will explain the essence of the method of *scope*. The inspiration of this concept comes from the “wave function” method in quantum mechanics (QM). However, there are still arguments of what wave function indeed is. For instance, all the existed forms of QM at present are only mathematical, the wave mechanics, the matrix mechanics, and the path-integral mechanics say few about the physical essence of the “quantum”. This may due to several reasons. Firstly, the math is quite abstract, say, what does a matrix mean? Why we need operator to describe an observable? Secondly, the objects and processes we observe in quantum physics are microscopic, so tiny that we can not make sure about our explanation. Thirdly, QM itself is not right or not complete. There should also be other reasons, all those things cause the “weirdness” of QM and the “confusion” of the interpretation. The reason why we need *scope* is mainly two folds. First, we can employ this concept to complete the form of QM. Second, scope is a new kind of universal description of motion. For example, we know from Newtonian mechanics that every motion associates with a certain *force*. Here, according to QM, we know that every motion has a certain *scope*. The method of scope can not only be used in QM, it is universal. So our construction is not limited within QM.

2.2 Theorem and Property

.

In this section we list the basic theorem and property of scope below. We should state that the proof may be given elsewhere.

THEOREM 1. Every motion has one Scope $\mathcal{S}$.

Here "motion" includes the condition when the observed velocity of one object is zero. Strictly, there is no object at rest. Scope $\mathcal{S}$ belongs to the motion of a certain object, not the object itself.

In addition, we should demonstrate that scope is not the same with the concept "matter wave" of de Broglie [1]. Matter wave is a kind of physical wave associated with the momentum. Actually, we do not think there is matter wave, we view it as a consequence of misunderstanding of QM.[1] The concept of scope describes the ability of motion in a systematical way.

THEOREM 2. Scope $\mathcal{S}$ is composed with state ψ_i with its weight α_i, where $i = 1, 2, ...n$, n decides the space of $\mathcal{S}$. ψ_i is a vector in the Hilbert space.

The concept of "state" originates from statistical physics and quantum mechanics. Within one scope $\mathcal{S}$, there can be many physical states ψ_i. One motion can only be in a state within its own scope. The relation between scope and state is expressed as the "**principle of superposition of scope**"

$$\mathcal{S}_n \equiv \sum_i^n \alpha_i \psi_i. \tag{2.1}$$

PROPERTY 1. Scope $\mathcal{S}$ has a certain geometrical shape.

The number of state n can not be zero. The states within the scope can form certain shape. For instance, if there is one single state, n=1, the corresponding shape of scope is just a point (in geometry). If n=2, the shape is one segment line, straight or carved, with a certain length. If n=3, the shape is one triangle face, with a certain area. If n=4, the shape is one tetrahedron. If $n \to \infty$, the shape is one ball. We should state that the shape is in the three-dimensional space, euclidian or non-euclidian, different from the shape in the high-dimensional space, such as the Hilbert space. The shape not only has the "shell" with boundary and face, also it has inner structure. Particularly, when $n \to \infty$, the ball can be viewed as one point if we neglect its structure. This is the alternative of the "classical limit" of the orthodox QM.

PROPERTY 2. Scope $\mathcal{S}$ has a certain magnitude.

The magnitude is defined as the length (or the area, the volume) of its shape. To calculate, we has to specialize the "distance" between different states. For

[1] Please read Chapter 3, 5, and 7.

instance, we can use the energy to define the distance $\mathcal{D}$, such as $\mathcal{D}(\psi_i, \psi_j) = |E_i - E_j|$.

The magnitudes of $\mathcal{S}$ of different movements should be different, since they have physical meanings. The bigger the magnitude, the better the ability of the motion, thus, more "freedom" in the scope $\mathcal{S}$. So, the magnitude is not necessarily equal to one, which is different with the normalization condition of the wave function in QM.

THEOREM 3. The shape of scope $\mathcal{S}$ could be influenced by mass $\mathcal{M}$.

This theorem sets the connection between the motion of a certain object and the object itself. It means that objects with different masses can not have the same scope. Every scope is unique.

This theorem also sets the connection between scope $\mathcal{S}$ and the method of Relativity. It means that the shape is not regularly euclidian. In general, it is topologically non-euclidian.

PROPERTY 3. One particular scope $\mathcal{S}$ has its own space-time matric.

This is the direct result of Theorem 3. When the effect of mass is not obvious, we can set the space-time matric of different scopes the same with each other, which is the classical limit.

THEOREM 4. There is a set of "active operator $\mathcal{A}$" which associates with $\mathcal{S}$ and satisfies

$$\mathcal{A}_i|\mathcal{S}\rangle = \alpha_i|\psi_i\rangle, i = 1, 2, ...n, \tag{2.2}$$

which means $\mathcal{A}_i$ can act state $|\psi_i\rangle$ out from scope $\mathcal{S}$.

$\mathcal{A}_i$ satisfies

$$\langle\mathcal{S}|\mathcal{A}_i|\mathcal{S}\rangle = \alpha_i\langle\mathcal{S}|\psi_i\rangle = |\alpha_i|^2, \tag{2.3}$$

which means $|\alpha_i|^2$ is the eigenvalue of the "activer" $\mathcal{A}_i$. This is the alternative of the "probabilistic interpretation" of the coefficients $|\alpha_i|^2$ in QM.

Also

$$\sum_i\langle\mathcal{S}|\mathcal{A}_i|\mathcal{S}\rangle = \langle\mathcal{S}|\sum_i\mathcal{A}_i|\mathcal{S}\rangle = 1 = \sum_i|\alpha_i|^2, \tag{2.4}$$

which means all the states are acted out, that is, the whole scope $\mathcal{S}$ is realized $\sum_i\langle\mathcal{S}|\mathcal{A}_i|\mathcal{S}\rangle = 1$, thus $\sum_i|\alpha_i|^2 = 1$. This is the origin of the normalization regulation. From the probabilistic view, it means the sum of all the probabilities equal to 1.

And, $(\mathcal{A}_i + \mathcal{A}_j)|\mathcal{S}\rangle = \alpha_i|\psi_i\rangle + \alpha_j|\psi_j\rangle = (\mathcal{A}_j + \mathcal{A}_i)|\mathcal{S}\rangle; \mathcal{A}_i\mathcal{A}_j|\mathcal{S}\rangle = 0, \mathcal{A}_i\mathcal{A}_j = 0, i \neq j; \mathcal{A}_i^2 = \mathcal{A}_i$. Also, there exists the "anti-active operator" 1-$\mathcal{A}_i \equiv \forall_i$.[2]

PROPERTY 4. The Scope $\mathcal{S}$ has the properties of "reality" and "propensity".

When $\mathcal{A}_i$ acts, the certain state $|\psi_i\rangle$ is realized, from potential to real, and the scope $\mathcal{S}$ "gradually evolves to its whole shape". There is the transition between reality and propensity.[3]

From this point, we know the concept $\mathcal{S}$ is totally new for classical physics. The local realism [3], the trump Einstein adopted to challenge QM, originates from classical physics. We view the "local realism" argument as the misunderstanding of the essence of QM.[4] This again demonstrates that scope $\mathcal{S}$ is a new kind of description, the "systematical" method, which is not the same with the classical dynamical method.

Also, the is no "collapse" thing [4]. Collapse means that when there is measurement, the state collapses from superposed state to the eigenstate. Or, some others view the collapse happens in our knowledge. In fact, with the process of decoherence [5], when the initial state is superposition state, it decoheres instead of collapse when there is measurement or environment.

THEOREM 5. The principle of superposition of state $|\psi\rangle$: the state of motion can be coherent superposition state

$$|\psi\rangle = \sum_j \beta_j|\psi_j\rangle, \sum_j |\beta_j|^2 = 1. \tag{2.5}$$

Here normalization means the norm of a state vector is 1, which is different with the property of scope.

PROPERTY 5. There are mainly two kinds of superposition states: time-quasistatic (Tq) state, such as the state in Rabi oscillation; ensemble-isotactic (Ei) state, such as the state in double-slit interference.

In the next chapter, we will give an example of the macroscopic superposition state. We will discuss the different classes of quantum states in Chapter 4 in detail.

---

[2]Here we do not discuss the properties of active operator in detail.

[3]Actually, the two aspects of scope were studied a long time ago by Aristoteles in the ancient Greece [2]. His gifted wisdom was mostly ignored and was claimed as a certain "metaphysical" method useless for physics.

[4]We will discuss this issue in Chapter 4 in detail.

THEOREM 6. There exist entanglement between two or multi-scopes.

For two systems, $\Psi_n\{a_i|\psi_i\rangle\}$, $\Phi_m\{b_j|\phi_j\rangle\}$, the entangle process $\mathbb{E}$ is

$$\sum_{i,j}^{n,m} \mathcal{A}_i^{\Psi}\{a_i|\psi_i\rangle\}\mathcal{A}_j^{\Phi}\{b_j|\phi_j\rangle\} \equiv \mathbb{E}, \tag{2.6}$$

according to the "**principle of entanglement**" (or **"1-1 branch" principle**)

$$\mathbb{E} \equiv \sum_{i}^{Min\{n,m\}} a_i b_i |\psi_i\rangle|\phi_i\rangle. \tag{2.7}$$

We will define the degree of entanglement $\mathcal{E}$ in Chapter 4. Also, there may be interactions during the entangle process, however, entanglement describes the information transition or correlations between different systems, instead of the energy transition. In addition, the detail which $|\psi_i\rangle$ is the "relative state" [6] to $|\phi_j\rangle$ is determined by nature.

PROPERTY 6. There are coherence between scopes and states. In fact, the universe is coherently entangled together as a whole.

This is the *inseparable* or the *wholeness* of the universe. The detail study of coherence is in Chapter 4. We demonstrate that the method of scope $\mathcal{S}$ describes the coherence and information process of the universe, thus manifests the physical essence of information.

PROPERTY 7. Measurement is a process of entanglement.

This is a simple result of the fact that the apparatus also has one scope with the states relative to the observed system. The measurement problem in QM, as well as the observe effect in Relativity, can be well explained with the method of entanglement, and the change of our knowledge is another story [7].

PROPERTY 8. There is consistency between the principle of entanglement and the principle of constant speed of light c.

We shall discuss this point in Chapter 5 in detail.

In the above, we outline the key theorems and properties of the method of scope $\mathcal{S}$, and we will discuss several problems in detail in the following chapters. In addition, we should point out that there is a natural connection between the methods of scope and yiang. In this work, we do not intend to study this profound issue in detail. Here what we demonstrate is that scope $\mathcal{S}$ lays the foundation of the new method, from which we can unify the methods of QM and Relativity in a certain way. To do so, we need to re-interpret both of them.

Bibliography

[1] L. de Broglie, *An Introduction to the Study of Wave Mechanics* (E. P. Dutton and Co., New York, 1930).

[2] Aristotle, *Metaphysics* (Oxford, Clarendon Press, 2006).

[3] A. Einstein, B. Podolsky, N. Rosen, *Can quantum-mechanical description of physical reality be considered complete?*, Phys. Rev. **47**, 777-780 (1935).

[4] J. von Neumann: *Mathematische Grundlagen der Quantnmechanik* (Springer, Berlin 1932), translated as *Mathematical Foundations of Quantum Mechanics* (Princeton University Press, 1955).

[5] W. H. Zurek, *Decoherence, einselection, and the quantum origins of the classical*, Rev. Mod. Phys. **75**, 715-775 (2003).

[6] H. Everett, *"Relative State" Formulation of Quantum Mechanics*, Rev. Mod. Phys. **29**, 454-462 (1957).

[7] B. d'Espagnat, *Consciousness and the Wigner's friend problem*, Found. Phys. **35**, 1943-1966 (2005).

Chapter 3

The Interpretation of Quantum Mechanics

3.1 Introduction

.

Quantum Mechanics (QM) has developed for more than one century, while the fundamental methods are still varying. This is, on one hand, due to its "weirdness", and on the other hand, the cooperation with Quantum Field theory and the theory of Relativity. Generally, we can study QM from three aspects: the mathematical theory, the interpretation, and the relativistic form. And we include the semi-classical theory in the first aspect, the problem of "classical" in the second aspect, the relativistic quantum mechanics and the quantum cosmology, which in fact exceeds the realm of QM, in the third aspect. In this chapter, we briefly studied the second aspect, the interpretation of QM.

As the development of mathematics and experiments, there have been lots of interpretations in history. In the era of the *old quantum theory*, there were already distinct explanations of "quanta". After 1928 the establishment of the *wave mechanics* and the *matrix mechanics*, Bohr and Heisenberg *etc.* (the Copenhagen School) formed the "Copenhagen Interpretation" [1, 2, 3]. Afterwards, von Neumann [4] raised the "problem of measurement" (*collapse*), based on his mathematical achievement, which is a central focus of QM. Then, various kinds of interpretations were formed. Everett [5, 6] put forward the concept of "relative state", and with the efforts of Dewitt [7], formed the "Many Worlds Interpretation" eventually. Bohm [8, 9, 10], based on the work of de Broglie, Einstein, Pauli etc., set up a kind of "Hidden Variables Theory" (HVT), which demonstrated the *incompleteness* of QM and the *certainty* of the motion of the micro-particles. Also, Griffiths [11, 12] raised the concept of "consistent history", with the efforts of Omnés [13, 14, 15], formed the"Consistent History Interpretation". They demonstrated the particularity of *quantum logic* and the inherent *randomness*. Pearle and

Gisin [16, 17, 18, 19, 20, 21, 22]*etc.* set up the physical theory of "collapse", they believed that the "wave function" is a real subject, and the Schrödinger equation should be amended to describe the problem of measurement. Cramer [23, 24, 25] raised the "Transaction Interpretation" to describe the dynamics, referred to the methods of the Field theory, he stated that QM is *nonlocal*, and the wave function represents the true wave interacted. Zeh [26] demonstrated the *openness* of QM originally, and Zurek [27, 28, 29, 30] focused on the study of "decoherence" etc., and explained the origin of *classical* quite successfully and the problem of measurement partly. And what's more, based on the concepts of "Einselection" and "Envariance", Zurek formed the "Existential Interpretation", which demonstrated the roles of "observe" and "information". There are also other interpretations, such as the "Modal Interpretation" formed by van Fraassen [31, 32, 33] etc., and the "Ithaca Interpretation" formed by Mermin [34, 35].

All the interpretations are developing, thus, it should be not the time to reach a completeness. There are both similarities and differences in these interpretations, and the mathematical methods they employ are different. Also, for the limitation of QM itself, such as the relation with the Relativity, the problem of "quantization", and the problem of "phase", an interpretation can only be relative complete. Then at present, many physicists just do not care about the interpretations, and the attitude is often "Do not ask, just calculate". In this chapter, we try to present the main concepts of each interpretation, and we examine the methods of QM under the concept of *scope* in detail, also we discuss the distinction of *quantum* and *classical*.

3.2 The Interpretations of QM

.

In this section, we mainly studied several interpretations, and then we examined several concepts which are useful in QM for our interpretation. What we concern is the fundamental concepts and methods, instead of mathematical forms.

3.2.1 Copenhagen Interpretation (CI)

.

Although this interpretation has existed for a long time, there still is not a refined version, for instance, there are confusion about whether the concept of *matter wave* (de Broglie), the *exclusion principle* (Pauli), the concept of *propensity* (Heisenberg), and the concept of *collapse* (von Neumann) should be included. Generally, the Copenhagen Interpretation includes these methods below.

(1) "Complementarity principle" (Bohr) and "Uncertainty relation" (Heisenberg). The complementarity principle states that the description of motion is

composed with several independent and correlated descriptions, any of them is incomplete. The behavior of particles should be descried with both particle and wave properties. In the language of Heisenberg, due to the influence of measurement, we can not simultaneously determine two quantities which are not commuted. In the experiment of two-slit interference, the property has been demonstrated. Each subject has the *matter wave*, with the wavelength $\lambda = h/p$. However, there are some difference between Bohr and Heisenberg. Bohr demonstrated the *complementarity* is a basic property of nature more, while Heisenberg more demonstrated the role of human being and the knowledge. Thus, for the problem "the uncertainty is extrinsic or intrinsic", there are divergence among physicists.

(2) "Statistical law" (Born). The wave function represents the "probability amplitude", the physical meaning is: $|\psi|^2 dr$ means the probability of the particle $\mathbf{r}$ to exist near $\mathrm{d}\mathbf{r}$, with $\int |\psi|^2 \mathrm{d}\mathbf{r}=1$.

When the system is eigenstate of dynamical variable, the outcome is fixed, and when the system is the superposition state, the outcome is statistical, this is the so-called "eigenvalue-eigenstate link" ("e-e link"). The statistical law confronted quite stiff problem when it was found originally, while it has played a central role in QM [36].

(3) "Correspondence principle" (Bohr). When the principal quantum number is quite big, or the Plank constant h tends zero, the quantum theory is the same with the classical theory, the latter as the approximation of the former. In fact, it divides the quantum world and the classical world. In the macro-realm, QM is not proper. However, the role of this "division" was not set up physically [28].

(4) "Collapse" (von Neumann). When measured, the state of the system collapses from the superposition state to the eigenstate. Thus, there exist two kinds of dynamics: the non-unitary collapse and unitary evolution under the Schrödinger equation. Also the collapse means the change of the knowledge of the observer. However, there are confusion about collapse. For example, Everett, Griffiths, and Bohm etc. viewed it as the mathematical form, while the "Physical Collapse Theory" and the dynamics of "Decoherence" try to explain it physically.

The Copenhagen Interpretation was formed almost at the same time with the mathematical form of QM. It explained the meaning of the wave function, the uncertainty between variables, the "classical" and so on. It demonstrated the role of "observe", as Heisenberg said: " What we observe is not nature itself, but the nature reflected with our minds" [2]. However, it can not explain questions such as "how the electron jumps?" due to the limitation of the mathematics. The wave function can only describe the "structure of motion", rather than the dynamics. Also, there is no eventual description of measurement.

3.2.2 Many Worlds Interpretation (MWI)

.

Everett raised the concept of "relative state" in order to make QM proper for the Quantum Cosmology [5]. Everett stated that the wave function is physical, and the whole universe can be described by one wave function. Due to the measurement of the observer, the wave function can "split" into many "branches", which are still correlated with each other. One state in one branch has the relative states in other branches, and the states of the branches are also correlated with the states of the observer. Afterwards, Dewitt, referred to the concepts of "preferred basis" and "decoherence", developed this interpretation [7]. We briefly sum up as follows.

(1) Quantum Mechanics is universal, there is no classical world beyond.

(2) The wave function is physical, it can not collapse into other wave functions, and its structure could split due to measurement into correlated branches, and the observer exists in one of the branches.

However, it has not focused on the origin of "statistics", and the observer seems can only exist within one of the branches. Recently, Zurek examined the essence of this interpretation, and made valuable improvement [29].

3.2.3 Consistent History Interpretation (CHI)

.

This interpretation demonstrated the speciality of the "Quantum Logic", which was originally raised by von Neumann [4]. And the problems of "representation" are related. Since the dynamical variables can be not commuted, thus, they can form different complete sets. We should encounter problems in measurement, such as whether " $S_z = +1/2$ *and* $S_x = +1/2$" is meaningful, which is obviously a logic problem. Griffiths found the concept of "consistent history" in order to surpass this problem [11]. "History" means a sequence of events at successive time, when it satisfies the "consistency conditions", it becomes the "consistent history" or "framework" ($\mathcal{F}$). Thus, if we want to prevent the measurement from meaningless, we should chose one $\mathcal{F}$. The $\mathcal{F}$ is the unification of logic and time. Its brief contents are shown below.

(1) The wave function is called "pre-probability", with no physical meaning. "Probability" means that of one certain "history". For instance, one $\mathcal{F}$ written as $Y = F_0 \odot F_1$, and the corresponding "chain operator" is $K(Y) = F_1 T(t_1, t_0) F_0$, the probability is $P = Tr(K^\dagger(Y)K(Y))$ [12].

(2) Quantum Mechanics is inherently random, and there is no "hidden variables", and the randomness is not caused by measurement.

(3) "Collapse" is a mathematical form without physical meaning. There is no "classicality", the "determinism" is a kind of approximation, can be used within limited realm.

(4) There can be several $\mathcal{F}$, they satisfy the "complementarity principle". The measurement within one $\mathcal{F}$ is equivalent with another.

(5) Quantum Logic is special. The judgement which does not satisfy the Quantum Logic or the "consistency conditions" is meaningless.

However, as the development of the interpretation of "consistent" and other concepts such as "coherence", this interpretation is still developing [30]. We demonstrate that it inherits lots of the basic methods of the orthodox interpretation, such as the meaning of wave function, the collapse, and the statistical, and what's more, it developed the method of representation. However, it has not reached one complete Quantum Logic.

3.2.4 Hidden Variable Theory and Bohmian Mechanics (BM)

.

In the early time of the quantum theory, Einstein criticized its completeness all the time, he thought that the statistical came from the ignorance of the fundamental physical process. This is also the origin of the concept of "hidden variable". Also, de Broglie and Schrödinger etc. viewed the wave function as the physical subject, "pilot wave", the particles "ride" the pilot wave, this picture was not developed much, however [8]. Einstein *etc.* raised the famous "EPR paradox" [37], afterwards, with the efforts of Bell [38, 39, 40], Aspect [41] etc., it has been verified that the local hidden variable is not proper. Thus, if there could be hidden variable, it must be non-local. *Non-locality* is one of the most active fields at present, and the resent developments, such as "teleportation" and "swapping", demonstrate that the "entangled state" is non-local, however, it does not verify the existence of hidden variable [42, 43].

On the contrary, Bohmian Mechanics serves as a kind of HVT, the coordinate of the particle is just the hidden variable. Except for the Schrödinger equation, it should also satisfy the "guiding equation" [9]

$$\dot{\mathbf{q}}_i = \frac{1}{m_i} Im(\frac{\psi^* \nabla_i \psi}{\psi^* \psi}). \tag{3.1}$$

For different initial conditions, there are different paths and fixed states in the phase space. What is more, Bohm raised the concept of *Quantum Potential*. If we write the wave function as $Re^{iS/\hbar}$, then the quantum potential is $U = -\frac{\hbar^2 \nabla^2 R}{2mR}$. It is strongly non-classical, and unfortunately, it is hard to define mathematically. Bohmian Mechanics describes a deterministic physical dynamics, it demonstrates the particle property, which is not the same with the orthodox interpretation. However, it is often viewed as a semi-classical method, without the essential meaning. However, we will state below that the dynamics of the micro-particle is one crucial aspect of the motion of the substance.

3.2.5 Transaction Interpretation (TI)

.

Cramer focused on the concept of "transaction" and formed a new kind of dynamics. "Transaction" describes the exchange of advanced and retarded waves between the emitter and the absorber, In the work [25], Cramer presented the detailed contents, and we briefly show as follows.

(1) The wave function is the real physical quantity, the "retarded wave".

(2) Transaction can describe the process of collapse.

(3) Transaction is nonlocal, and satisfies "the principle of Relativity".

(4) The "Uncertainty relation" means that the transaction can project out only one of a pair of conjugate variables. The offer wave is wavelike, the completed transaction is particle-like, which can localize special components of the offer wave function.

(5) The "echo" received by the emitter initiating the transaction follows the Born probability.

(6) Transaction includes emission, response, stochastic choice, and repetition to completion. The physical process is random.

(7) There is no distinction of *quantum* and *classical*, the basic physical process is universal, that is,"transaction".

(8) There are two kinds of quantities: the "observable" and the "inferred quantities", the former can be predicted and subjected to experimental verification, and the latter is complex which can not be verified.

We can see that this method referred to the idea of the Field theory, it introduced the motion of the field to describe the dynamics. In fact, it describes the motion of two subjects: the particle and the wave. Obviously, it could be viewed as a kind of developed form of the "pilot wave" (de Broglie) [25].

3.2.6 Physical Collapse Theory (PCT)

.

Generally, this theory is viewed as one semi-classical method, however, it is also a kind of interpretation. Originally, Pearle [16, 17, 18] and Gisin [19] put forward the "stochastic dynamical reduction". The wave function evolved spontaneously from the superposition state to the eignstate, by adding one nonlinear term, the "white noise", causing $|C_n(t)|^2$ fluctuate, then, one of them tends 1, others tend 0. Afterwards, Ghirardi, Rimini and Weber (GRW) [20] set up the "spontaneous localization model". The Gaussian wave packet could spontaneously localized without the effect of environment. This kind of irreversible process was supposed as one of the fundamental motion of the particle. Also, the "continuous spontaneous localization model" was established. Although this method does not intend to form a kind of interpretation, it still includes several distinct properties shown as below.

(1) The wave function is the real physical quantity, the "wave packet".

(2) The Schrödinger equation is incomplete, it can not describe the collapse.

Also, the collapse is real process, thus, the separation of *quantum* and *classical* is broken.

(3) The system is generalized from closed to open, by introducing the "relaxation" and "noise".

(4) The "wave-particle duality" is reflected by the movement of the wave packet.

In all, it does not present a fundamental meaning of collapse and other problems, such as "classicality", " complementarity principle ". However, the mathematics is quite powerful, and it is similar with the master equation of the method of decoherence.

3.2.7 Decoherence and Exsistential Interpretation (EI)

.

Decoherence is caused by the entanglement between the system and the environment (observer). This property of "openness" was originally studied by Zeh [26], and then Zurek [27, 28, 29] developed it. We can study this method from several aspects below.

(1) Quantum Mechanics is universal. Thus, the observer, apparatus, and the environment etc. can be described by the wave function.

(2) The wave function is the "probability amplitude", satisfying the "superposition principle", and it is not physical.

(3) The orthodox interpretation does not study the problem of "initial state", while Zurek found the concept of "Einselection", which means the entanglement between the system S and the environment E "superselect" the initial state, named as the "preferred basis". It is the eignstate $|s_i\rangle$, and the dynamical variable O satisfies $\langle O\rangle = \sum o_i|s_i\rangle\langle s_i|$, $[O, H] = 0$.

(4) Decoherence causes collapse. The *quantum* and *classical* are connected by decoherence, and the classical states are one special part of the quantum states. This is more fundamental than the mathematical method of the "correspondence principle".

(5) "Statistical" can be deduced with the reduced density matrix. In order to observe the state of the system, we need to trace the variables of the environment, $\rho_s = \sum_{nn'} c_n c^*_{n'}|s_n\rangle\langle s_{n'}|\langle E_{n'}|E_n\rangle \to \sum_n |c_n|^2|s_n\rangle\langle s_n|$. The outcome is statistical. Also, without using the reduced density matrix, Zurek has deduced the statistical with the method of "Envariance" [28].

(6) The "complementarity principle" and "wave-particle duality" can be interpreted with entanglement and information. When the observer can distinguish the relative states of the system, the information of the system flows to the environment and is memorized, and it shows the particle property. On the contrary, when the information remains in the system, it shows the wave property.

(7) Decoherence is different from "relaxation" and "noise". Decoherence is

due to the disturbance of the system to the environment, it means the change of "local phase" and the motion of information. While relaxation is due to the disturbance of the environment to the system, which is not coherent, and there should be exchange of energy.

However, decoherence has not solved the problem of measurement totally. Although it can define the real states, it can not define which state is realized under each measurement. And the study is still going on [28, 30].

What is more, based on the concepts of "Einselection" and "Envariance" etc., Zurek formed the "Existential Interpretation". "Einselection" means the "pointer state" is the most robust relative to the disturbance of the environment, this is a kind of evolution, named as the "Quantum Darwinism". Also, Zurek demonstrated the fundamental role of "observe" and "information". What is known by the observer can not be separated with the observer itself, and the "memory states" of the observer are correlated with the information from the universe. After decoherence, only the "pointer states" remain and keep correlation. And, Zurek also absorbed the essence of the Many Worlds interpretation, and solved its problems. The memory states are connected with different branches of the universe, which are determined by "Einselection".

In all, there are similarities and differences between these interpretations, we do not intend to compare them in detail. Instead, we form the main methods of each interpretation into a table, shown in Sec. 3.5 C.

3.2.8 Other Concepts

.

What is more, there are also other interpretations and some valuable concepts, below, we mainly focus on the study of several valuable concepts.

(1) "Propensity". Heisenberg originally referred to the concept of "propensity" of Aristoteles. In the book *meta-physics*, Aristoteles stated that there are two forms of existence of substance: "reality" and "propensity". Propensity is a kind of ability or potential to change itself or others, it is one property of the substance, and it is not subjective [44]. Heisenberg stated that the wave function is the mixture of two things: one is the fact, the other is the knowledge of us about the fact, after measurement, the wave function changes from propensity to fact [2]. Also, Margenaua and Popper [45] etc. employed the concept of propensity. However, we should pay attention to the origin of the propensity, that is, reflection of a value of the property does not mean there is one property. Thus, we should exclude the unwanted possibility. Heisenberg valued the role of the observer much more, and also the interaction between the observer and the system. While, the concept of propensity of Aristoteles is not related to the observer, which only means the property of the external substance. In fact, it is the observer who introduces the

unwanted possibility, which should be excluded. In all, the wave function is a mixture of the fact and that would be the fact.

(2) "Ignorance". When the observer does not know the states of the system, the state can be written as a mixture $\sum_i p_i \psi_i \psi_i^*$, where p_i are known. "Ignorance" is also a property of complementarity. The more we know about the system as a whole, the less we know the inner states. Of course, we can realize a kind of "intermediate state", that we can know both the whole and the parts. "Ignorance" also relates to the process of information, obviously.

(3) "True" and "Reliable". Cramer studied these two concepts in detail originally[25]. When the observer intends to observe the part S of the whole SE, before the measurement, the property of S is "reliable", and after that the property turns to "true". It is consistent with the concepts of "propensity" and "ignorance".

(4) "Modal". van Fraassen, as a "constructive empiricist", formed the "Modal Interpretation" [31]. It states that the reality is constructed. When we measure, the entangled state formed is a new kind of reality. And the reason that we get the statistical outcome is due to our ignorance. Also, there is no so-called collapse. Afterwards, Kochen, Healey, and Dieks [32, 33] etc. made some further efforts. However, the problem of measurement can not be solved. Briefly, the concept of "modal" demonstrated the correlation and entanglement of QM.

(5) "Correlation without correlata". This concept was raised by Mermin [34, 35], who formed the "Ithaca Interpretation". It stated that the reality is "correlation" rather than the "correlata" which are correlated. Quantum Mechanics describes the independent correlation. This is consistent with the method of "modal". In fact, it is the reflection of "non-locality".

(6) Contextuality. Bell [39] firstly used this concept when studying the "hidden variables theory", and after that, Simony [46] etc. developed it. Particularly, one "context" means a complete set with commuted dynamical variables. And the dynamical variables should be "time-like", satisfying the principle of Relativity. We should notice that the "context" has the similar property with the "consistent history".

We have to state that there still exist some confusion about these concepts, which we do not study in detail, however. We will use these concepts for the interpretation of QM below.

3.3 The Methods of Physics and Some Basic Concepts

.

Before we discuss the methods of QM in detail, we have to clarify the basic methods of physics, also some crucial concepts in QM.

Physics is the combination of experiments and mathematics, which requests the accordance of theory and observe. However, on the problem whether the accordance can be the real motion of the reality, physics can not answer. Physics is a mean of our human being to study nature, and then a knowledge system. It can not deny the movability of the substance, in principle. In the early time of QM, people tend to demonstrate the role of observer much more, for example, some held that " the moon is not there when we do not see it", and others held a rather compromise standpoint, such as the "constructive empiricism" of van Fraassen. However, the activity of our human being is also objective following some laws. Eventually, what we study is indeed the reality itself, and our knowledge is the reflection of the objective laws. Also, we have to demonstrate that the functions in physics describes the "motion", not the matter itself. In the early time, de Broglie and Schrödinger suggested that the electron is disperse [8], which was verified as not proper. In the macro-realm, we can see the object directly, however, it is impossible to see a micro-particle. The wave function describes the motion of particle rather than the particle itself.

As the knowledge of the structure and motion of the substance developing, there mainly exist four kinds of methods to describe the motion (please see Chapter 1). Here we demonstrate again their essence. Firstly, in Classical Mechanics (CM), any interaction is external and casual, the mass point or the system of mass points moves along fixed path under the drive of external forces in the space and time dynamically. Further, the Analytical Mechanics explained the dynamics from the view of "energy", and the "certainty" and "casuality" remain. The second one is the thermodynamics and statistics. For the gas or liquid, it is quite hard to describe the motion with CM. Physicists found the method of "statistics" to describe the "collective motion". However, often the method is viewed as a kind of ignorance of the observer, since the exact state of a certain particle can not be determined. While, we emphasize that this kind of "ignorance" is inevitable. If we follow the track of each particle (such as the "Maxwell demon"), we may destroy the state of the system (introducing "entropy"), thus, we can not get the real state of the system. In fact, the method of *statistical* is equal with the *dynamical* method. The statistical laws are also the reflection of nature. Quantum Mechanics (QM) is indeed another kind of new method, which mainly focus on the study of the matter with limited structures such as the atoms, electrons, and nuclear etc.. Almost all the motion in the micro-realm is finite and limited, thus, "quantum". If the "finiteness" is destroyed, for example, when the atom is broken into pieces, the electron becomes free, then it can also be describes with CM. Further, the many-body problems, such as the structure of atom, are the central problems of QM. It means that the motion is "systematic", rather than single or collective, similar with the nonlinear dynamics. The "wave function" is a kind of "integral" description of the "structure of motion", rather than the dynamics. It can only result the statistical outcomes, without knowing the underlying dynamics of the particles. Actually, we can introduce some kind of dynamics, such as the Bohmian Mechanics. The problem of "completeness" and "hidden variable" of QM are due to the difference of the methods of description of motion. Thus, we can generalize the method of wave function to other research objects, that is to say, this method is universal. We have seen that it has already been applied to describe the motion of elementary particle and field. The forth method is "field". The motion of the field is a coherent "compound motion" of many identical particles.

What is more, these four different methods are "complementary", they each can be applied to describe motion in any scale, microscopic, macroscopic, etc.. It is not the issue of "true or false", only of "good or bad", the problem of "efficiency" to employ which method. Different descriptions are one aspect of the same motion, and they together form a complete description, this property can be named as the "integrity principle".[1] We should notice that it is different from the "complementarity principle", here, the description is not mutually exclusive, and they can exist at the same time.

After we examine the description of the methods of QM, we hereafter talk about several fundamental concepts in it.

(1) "Wave". The concept of "wave" has existed from the time of Newton, and entangled with the concept of "particle" even till now. For instance, Newton stated that the light is particle, while Huygens verified that the light is wave. In thermodynamics, the transfer of energy is thought in the way of wave. The motion of wave needs the "medium", and it is the "collective motion" of many particles. While, the electromagnetic wave is viewed as a kind of wave which does not need the medium since it is a kind of matter itself. According to the Field theory, the elementary particle of the electromagnetic field is "photon", which is a packet of energy. All the micro-particles have the property of "wave-particle duality", as the double-slit interference experiment has shown. It satisfies $m\lambda = h/c$, where m is mass, represents the particle property, λ is the wavelength of the matter wave, represents the property of wave, h is the Planck constant, c is the speed of light in vacuum. What is more, the "Uncertainty relation" reflects the property of the motion of the particles, the unification of "individuality"' and "collectivity", we named as "systematics". It is not related to the structure of the particle itself.

In all, the particle property means the "individuality", and the wave property means the "collectivity", which are unified as the "systematics". "Wave" is a kind of motion rather than a kind of matter itself. Commonly, we say that the "field" is a kind of matter, indeed, it means that the element of the field is a kind of matter.

(2) "Information". From the concept of "entropy", information has already been studied for a long time till Shannon, who defined information as the "negentropy". Information is a statistical concept, it is neither matter nor energy, but a kind of motion of them. When the state of the matter does not change, there should be no information. In QM, it is connected with the entanglement.

[1] Or *the principle of harmony of the principles of the universe* formed in Chapter 8.

Within an entangled state, the information is shared by the parties. For instance, the information can flow from the system to the environment, then the particle property of the system is observed. When the information stays within the system, then the wave property is observed. And the total amount of information is conserved. Further, the "second law of thermodynamics", or the "principle of entropy increase", is connected with the entanglement. The entropy of the closed system tends maximum, while for the open system, the "flow of entropy" should move among the several subsystems [47].

Further, one more fundamental question is: can information be duplicated? Experience tells us that *yes*. However, there should be tiny changes with each duplication. Thus, strictly speaking, the information can multiply rather than be duplicated. The property of "multiplication" is not conflict with the "conservation" above. "Multiplication" is a kind of many-body problem, that is, many states "converge" resulting in the multiplication of special information, and at the same time, the reduction of other information. For instance, when we copy some documents, the information of the documents multiplies, while the characters of the papers are destroyed. Thus, the total amount of information keeps conserved. For another instance, during the purification of noisy entanglement, the total amount of information we should consider is conserved, while the state we need is multiplied, the other information is consumed [48, 49]. In all, information is a kind of conserved motion of matter and energy. The reason of the conservation is based on the fact that the matter and energy are conserved themselves.[2]

(3) "Interaction". There exist interactions among objects. The transformation of information needs some kind of interaction, and the things transferred can be matter, energy or symbols. On the contrary, when there is interaction, there is not necessarily information since the system may has reached the stationary state. For instance, the entangled pair of photons. When the two photons are separated far away, as long as the stability, the entanglement remain, there will be no information to be transferred, without conflict with the principle of Relativity. The "non-locality" is due to the interaction within the entangled states, for example, the "transaction" can well explain this property [25]. As we know, there are four kinds of interactions: gravitational, electromagnetic, weak, and strong interactions which differ with each other due to that the basic elements of substance are diverse. In QM, the electromagnetic plays the central role. There exists electromagnetic force between the entangled photons, or the electrons in the double-slit experiment. In all, the "non-locality", also the "coherence", are due to the interaction within the field, since the field itself is a kind of nonlocal compact entity.[3]

[2] Further study of information related with yiang is presented in Chapter 6.

[3] We should state that at present stage, we employ the method of "non-locality". However, this method will be proven to be not proper in Chapter 4.

3.4 The Methods of QM

.

Based on what we studied above, in this section, we try to examine the basic methods of QM, and introduce our comprehension. We mainly study the meaning of the wave function, classicality, statistics, systematics (Quantum Logic), casuality and the problem of measurement. We present our study from four aspects: the kinematics, the dynamics, the many-body problem, and the macro-motion.

3.4.1 Kinematics

.

(1) What is the wave function?

The wave function Ψ is an integral description of motion, which is in fact the "Scope" of motion.[4] It describes the "structure of motion", and the correlations among states and observable, rather than the casual dynamics. It has properties as below.

a. Ψ is complex. In order to describe the special movement, the "representation" is needed for calculation, named as "the scope under representation".

b. Ψ is composed with "state", written as

$$\Psi^n \equiv \{c_1\psi_1, c_2\psi_2, ..., c_n\psi_n\}, \tag{3.2}$$

where ψ is "state", satisfying $\langle\psi_i|\psi_j\rangle = 0$, c_i is complex, which means the "weight" of ψ_i, satisfying $\sum_i |c_i|^2 = 1$. n is the dimension of the scope. Ψ can be mathematically written as the superposition of states within as $\sum_i c_i\psi_i$, and one state can also be written as the superposition of other coherent states. That is to say, the "principle of superposition" includes two aspects: the superposition of "scope" and the superposition of "state". Although both of them can be represented by a "vector", they have distinct meanings, however. This is the core of our interpretation.[5]

c. Ψ satisfies all the operations of vector , such as addition, subtraction, multiplication, cross product, and dot product.

d. Ψ is "counterfactual" including two aspects: the reality and the propensity, which are complementary as the reflection of "integrity" and "systematics". While, the state ψ is "factual", which can be really measured.

e. The scope Ψ satisfies the Schrödinger equation

$$i\hbar\frac{\partial\Psi}{\partial t} = \mathcal{H}\Psi, \tag{3.3}$$

where $\mathcal{H}$ is the Hamiltonian. The solution of this equation is the "structure of the motion". The solutions satisfy the "variation principle". We should note that "t"

[4]We can both use the symbols Ψ and $\mathcal{S}$ to describe scope.

[5]Please read Chapter 2, the theorems and properties.

means the change of space rather than the evolution of time. In fact, "t" means the "gradually evolving of the scope".

f. The space of ψ is Hilbert Space, including the finite and infinite dimension, corresponding with the finite motion and infinite motion, relatively. The energy of the infinite motion can be viewed as continuous.

g. All the states ψ are "time-like" satisfying the principle of Relativity, also they satisfy the "ergodic theorem" which means the "time average" is equal with the "ensemble average".

h. There are definite phases with all the states ψ, thus they can interfere with each other.[6]

i. The actual system can be "superposition state", which is a kind of "homeostasis". For instance, the Rabi Oscillation of the two level system controlled with pulses is one superposition state.

j. "The density matrix" is $\rho = |\psi\rangle\langle\psi|$, the diagonal elements $|c_i|^2$ are "population" or "probability", the non-diagonal elements $c_i c_j$ are "coherence", which tends zero when decoherence occurs.

k. The density matrix satisfies the Liouville equation

$$\dot{\rho} = [\mathcal{H}, \rho]/i\hbar. \tag{3.4}$$

We can get the "probability" and "coherence". This equation is the equivalence of the Schrödinger Equation.

(2) Operator.

a. Picture. The origin of "picture" is due to the difference of the frame, also it connects with the problem of "time". Generally, there are already three kinds of pictures as follows.

The frame is set on the motion itself: Schrödinger picture. The dynamical variables do not change with time, there is one static dynamical variable with each state. The time "t" in the Schrödinger equation means the expand of the scope.

The frame is set external: Heisenberg picture. The dynamical variable satisfies

$$\dot{A}(t) = -[\mathcal{H}, A(t)]/i\hbar. \tag{3.5}$$

It means the change of dynamical variable in different states in the fixed scope.

The frame is set in-between: Dirac picture. $\Psi_I(t) = e^{i\mathcal{H}_0 t/\hbar}\Psi_S(t)$, $A_I(t) = e^{i\mathcal{H}_0 t/\hbar}A_S e^{-i\mathcal{H}_0 t/\hbar}$, satisfying

$$\begin{aligned} i\hbar\dot{\Psi}_I(t) &= \mathcal{H}_I\Psi_I(t), \\ i\hbar\dot{A}_I(t) &= -[\mathcal{H}, A_I(t)], \end{aligned} \tag{3.6}$$

where $\mathcal{H} = \mathcal{H}_0 + \mathcal{H}'$.

[6] About the problem of "phase", we do not discuss here.

b. The eigenequation of the dynamical variable is $A\psi_i = a_i\psi_i$. There is "degeneracy" among the eigenstates. For the classical motion, the degree of degeneracy can be infinite, for instance, the motion of the subject with the same energy can be circular and also uniform, and the energy is continuous, the motion is infinite [50]. On the contrary, the quantum motion is finite, the degree of symmetry is quite small, also the degeneracy. In fact, this shows the limitation of the method of energy, since it can not well distinguish states.

c. The Uncertainty relation: $\Delta A \Delta B \geq \langle |[A, B]| \rangle / 2$. It describes the complementary relation of two non-commuted dynamical variables within the scope. It is not caused by the measurement, in principle. For instance, we can define the coordinate exactly of the particle, then we can not define its momentum. Also we can both measure its coordinate and momentum as long as satisfying this relation.

d. The "wave-particle duality". The particle property means "individuality", and the wave property means "collectivity", unified as "systematics", satisfying $m\lambda = h/c$, both of them describe the "motion" of the subject rather than "itself", it has nothing to do with "the structure of the particle".

About $\Delta x \Delta p \geq \hbar/2$. It can not only be applied in the micro-realm, also the macro-realm. For example, in the macro motion, when $\Delta x \to 0$, $\frac{\partial}{\partial x} \to \infty$, it means when the coordinate is defined, the momentum can not be defined. However, we can use the mathematical theory of *limitation* to define the "instantaneous velocity", and $h \to 0$, then it only need $\Delta x \Delta p \geq 0$, thus, the momentum can also be defined. This is a kind of approximation mathematically, not physically. On the contrary, for the quantum motion, when the coordinate is defined, the particle is totally local, thus, the knowledge about the integral behavior tends zero, and the corresponding uncertainty or non-locality of momentum is big. This relation shows the antinomy between "local" and "nonlocal", also "individual" and "collective".

About $\Delta E \Delta t \geq \hbar/2$. It means that the particle needs time Δt to "complete" the scope of energy ΔE. For instance, the life of the particle can be interpreted in this way.

e. Representation, Complete set, and "Framework"($\mathcal{F}$). When measurement occurs, "the scope under representation", the complete set composed with commuted dynamical variables are chosen. Physically, when a set of movements satisfy the "consistency condition", they form one $\mathcal{F}$ [11]. Different complete sets and different $\mathcal{F}$ are all compatible.

f. Quantum Logic. The basic element of QM is "algebra", which is a structure of "number". Quantum Logic is not the logic of "number", it is the logic of "algebra". It is integral, and describes the relation of different structures. What is more, the dynamical variables can form *group*, satisfying $[A, B] = AB - BA$, $[[A, B], C] + [[C, A], B] + [[B, C], A] = 0$, for instance. However, a complete Quantum Logic still needs lots of efforts to solve problems, such as the "quantization", which is left to be an open question.

3.4.2 Dynamics

.

We have stated that there are four kinds of methods to describe the motion. The description of "scope" is relative complete, it only describes the integral and systematic structure (or logic) of motion, it can not be used to describe the dynamics and the particle property. In the early time of QM, the efficiency of "casuality" was questioned, and instigated prolong discussions on basic concepts [51]. However, we state that the objective laws do exist, and the motion is independent and individual, the casuality is universal. The Bohmian Mechanics gives an excellent answer in QM. We have to point out that there exist some difference between our interpretation and the Bohmian Mechanics. The so-called "pilot wave" is indeed "scope", describing the integral behavior of particle. The reason that we have to describe the integral behavior rather than to describe the dynamics only as the Newton equation is that all the motion of micro-particle is within the coherent field, and the scope is easy to be realized by particles with different initial states. Thus, it is practical to view the limitation of scope as the interaction of the real field. The path of the particle is strongly non-classical. The "transaction" studied by Cramer [25] is also the effect of the real field. Also, the semi-classical methods, such as the "Physical Collapse Theory" and the "Wigner Function" etc., use "wave packet" to describe the particle, which moves in the space-time with both coordinate and momentum. In fact, it unifies the "individuality" and "collectivity", thus, it is also very useful. However, we should state that the particle itself is not a wave packet, which only describe the motion of the particle. We see that there can be several dynamical semi-classical methods, but only one, the Bohmian Mechanics, can truly reflect the casual dynamics of each distinct particle. In all, the dynamics reflects the casuality, and the method of scope can describe the integrity of motion.

3.4.3 Many-body Problem

.

(1) The principle of identity. The micro-particle has the property of identity, this is the foundation of Quantum Statistical Mechanics. In addition, the relation between "spin" and "statistics" is not within the realm of QM, we should not discuss it here.

(2) Entanglement. The basic form of interaction between scopes is "entanglement". The "state" can not be entangled, only "scope" can. The entangled state is a result of the entanglement between scopes. For instance, if $\Psi_x = \{x_1, x_2, ...\}$, $\Psi_y = \{y_1, y_2, ...\}$, $\Psi_z = \{z_1, z_2, ...\}$, where the coefficients are not specialized. The entanglement can be written as

$$\Psi_x \infty \Psi_y \infty \Psi_z = x_1 y_1 z_1 + x_2 y_2 z_2 + ... + x_2 y_1 z_1 + x_1 y_2 z_1 + ... + ..., \tag{3.7}$$

where ∞ represents the entangle operator, x, y, z represent different states. The entangled state is divided due to "symmetry" into different entangled states. That is to say, when entanglement occurs, the states interact with each other due to symmetry since the state with certain symmetry is static. For example, the "Bell-states basis" $\frac{1}{\sqrt{2}}(|00\rangle \pm |11\rangle)$, $\frac{1}{\sqrt{2}}(|01\rangle \pm |10\rangle)$, are the entangled states of a pair of two-dimension scopes due to the symmetry of exchange (permutation). The entangled state can occupy quite a big space of the coordinate or the momentum. As long as the entanglement remains, there is no information needed to transfer since the information has already been shared.

(3) Measurement. Measurement can cause entanglement and the non-unitary evolution of the system. We describe it often with the Lindblad Equation

$$i\hbar\dot{\rho} = [\mathcal{H}, \rho] + (L^+ L\rho + LL^+\rho + L^+\rho L). \tag{3.8}$$

After decoherence, if we observe, we can only get the statistical outcomes. The *classical* is one particular part of the *quantum* world. In addition, the continuous measurement can stop or accelerate the evolution, such as the Quantum Zeno effect [52].

(4) Mixed state. The mixed state is a mixture of a mount of scopes which are not coherent, in fact, it is a part of a bigger scope, that is, a part of a "pure state". Often, it can be written as $\rho = \sum_i p_i \rho_i$, satisfying $\sum_i p_i = 1$.

(5) Many body movements, such as the strong correlated electrons, the structure of atom. It shows obvious non-linear property for its systematics. Thus, it is natural to describe it with the method of scope.

3.4.4 Macroscopic motion

.

Macro-subject often moves under the gravity or electromagnetic force. The Newton equation and the Einstein Field equation are both casual and real. And, the motion can also be described by scope. In the macro-realm, the "Many Worlds Interpretation" is more proper than the statistical interpretation in the Quantum Cosmology. The reason is that the "branches" just form the scope to describe the integral state of the whole universe. In the macro-realm, the classical state ($\mathbf{p}$, $\mathbf{r}$) is just one state of the whole scope, which can be transferred to other potential states with coherent manners, such as the rocket. The classical state is one kind of quantum state after the decoherence, however, the nature and ability of "coherence" or "correlation" remain, only changes from "reality" to "propensity". When measured, the coherence can be active again. Further, there is not only coherence in the microscopic realm, also in the macroscopic gravity field. All the motion within field is essentially coherent, thus, all the motion can be described by scope. Particularly, the subject can stay on one state, such as the potential energy surface, with stationary energy. But, one obvious question one can ask is that: the classical state in our daily life is changing all the time! From the view of scope, the subject, the car for instance, does not change its state though its velocity is changing, this change is relative to the observer only. We can name the state as "inner state", since one subject can only move within its own scope. The observer exists in his/her scope, the car exists in its scope, too. The interaction between them is "entanglement". The so-called interactions in our daily life are all a part of the bigger entangled state. What is more, this kind of inner interaction satisfies the principle of Relativity.[7] If the car is not driven by external force, it will keep static or uniform along a line (a circular, in fact). Due to the interaction between the observer and the car, the observer can measure the change of the state of the car. However, this change is just a kind of "random fluctuation" relative to the scope of the car. After all, the car does not leave the surface of the earth to go into the universe. And obviously, we can introduce the dynamical method, the Newtonian mechanics, to describe this kind of fluctuation.

In all, all the motion of substance in the universe can be described by the method of scope, all the motion has one scope, and all the motion has the property of integrity, which is the complementary unification of "individuality" and "collectivity".[8] The "uncertainty" and "randomness" are the reflection of the incompleteness of the method of description, which is a kind of "ignorance". We state that the motion of substance is certain and can be determined, which is the core of causality. The methods in classical physics, such as "mass point" and "path", can also be used to describe the motion of micro-particles (Bohm [9]). And, the so-called *quantum* and *classical* should be viewed differently, the difference is only due to the difference of description. That is to say, the quantum world and the classical world are the same, only with distinct languages.

3.5 Appendix

.

A. The classical example of the "superposition state".

One of the main point of the work is that there is no the so-called "quantum" or "classical". In fact, all the motion of the substance is integral and systematic, as the unification of "individuality" and "collectivity". There are certainly superposition state in the macro-realm, we give just one example below.

Suppose one coin is in a closed ball, such as the "piggy bank", now let it move freely.

From statistics, when the ball stops, the state of the coin is either the "front" $|\psi_1\rangle$ or the "back" $|\psi_2\rangle$.

[7] For the relation between Quantum mechanics and Relativity, please read Chapter 6.

[8] This is the generalization of the *wave-particle duality*.

If we do experiment just with this device for almost infinite times, that is $t \to \infty$, then we get the probabilities $P(|\psi_1\rangle) = 1/2, P(|\psi_2\rangle) = 1/2$, obviously.

If we use almost infinite the same devices to do experiments, then we get the same result with the former case, this is the "ergodic theorem".

The origin of "statistics" is the measurement of the observer, which means $|\psi_1\rangle|E\rangle \to |\psi_1\rangle|E_1\rangle, |\psi_2\rangle|E\rangle \to |\psi_2\rangle|E_2\rangle$, where $|E_1\rangle, |E_2\rangle$ are the "memory states" of the observer (pointer state). This is also the so-called "collapse", and the "knowledge" of the observer is changed.

The reason that we can just observe two states is that there are two faces of a coin, the front and the back, which are the "eigenstate". The state is quantized, obviously.

Then, if we do not disturb the ball, the state of the coin is just the "superposition state", which is $(|\psi_1\rangle + |\psi_2\rangle)/\sqrt{2}$.

If we measure it, one way is to stop it, then we get the states "front" or "back", and the memory state of us is $|E_1\rangle$ or $|E_2\rangle$. Also, these states are orthogonal and "local".

If the ball is transparent, the observer can "see" the "superposition state" without disturbing it, the coin shows the wave property. "Seeing", which is easy to realized in macro-realm for we are macroscopic ourselves, it is hard to realize in the micro-realm, however. In principle, it can be realized. Also, we should notice that when we see it, we can see infinite different kinds of potential superposition, as there is "ignorance" of observer, this potential is not the same with the "propensity" of the system, the coin. In order to diminish the ignorance of the observer, we have to do lots of experiments or destroy its state. Also, we can get a kind of "intermediate state" with both the particle and the wave properties. For instance, we can make the ball slow down or move regularly, while at the same time keep the coin rolling. Thus, we can not only observe that the coin has two faces, and also it keeps "jumping" from one to another. This is a kind of "homeostasis". This kind of measurement is often named as the "weak measurement", also the states of the coin and the observer can be both named as "weak superposition state".

Further, how can we define the initial state of the coin, the eigenstate or the superposition state? Both of them is static satisfying the "variation principle", while the former one is stationary, the latter one is homeostasis. In nature, both of them can exist, for example, in the complex system, the homeostasis is common. While, in the simple systems in physics, the common state is the local eigenstate, and often they relax to the "ground state". However, we can change the state with "artificial" manners such as the laser, from one stationary state to another, or make it keep jumping then forming a superposition state.

The wave function is in fact a "scope", which is the integral description of the motion. For the example above, we know little about the dynamics of the coin. We have to introduce a kind of casual dynamics to describe it. The reason QM viewing the dynamics as "intrinsic random" is that the description of "scope" is

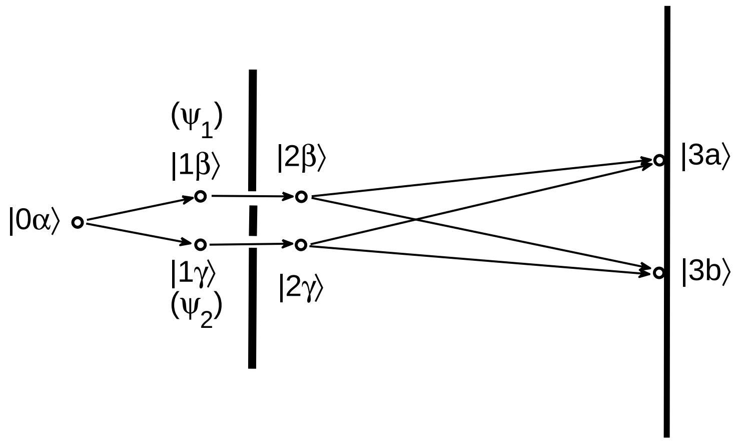


Figure 3.1: The experiment of double-slit interference. ψ_1,ψ_2 represent the states of electron near the slits. Other notations represent the states of the "consistent history", see the text.

not enough. And, what is more, the scope is not given initially, it is reached by lots of experiments, this is just the process we named as "the scope is gradually evolving". In the micro-realm, as the motion is more "limited", the scope is quite "small" so that it is easy for the micro-particle to realize its scope, which is the so-called "quantum phenomenon". While in the macro-realm, the scope is quite "big", and our human being as the observer staying at one of the eigenstate in the scope, thus, it is hard for us to observe the motion across the whole scope, which causes the so-called "classical phenomenon". This should be viewed as a kind of symmetry since no matter what the scale is, there always exist scope. The difference is that the fields underlying are different, the electromagnetic field or the gravity field etc., which is the focus of the field theory beyond the realm of QM.

B. The experiment of double-slit interference.

As shown in Figure 3.1, this experiment is fundamental in QM, since it can fully reflect the property of the particle, such as electron. However, different interpretations give different descriptions. In addition, the Field theory also give a picture based on the method of "propagator", which is not presented here. We just briefly compared the methods below.

a. Copenhagen.

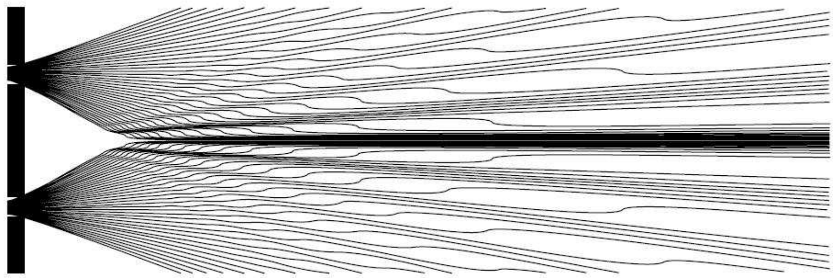


Figure 3.2: Bohmian Mechanics, from [53]. The wavy lines represent the paths of particles.

The wave function of electron is $\psi = \psi_1 + \psi_2$, the probability of the electron to reach the screen is $|\psi|^2 = |\psi_1 + \psi_2|^2 = |\psi_1|^2 + |\psi_2|^2 + 2Re(\langle\psi_1^*|\psi_2\rangle)$. The interference term is not zero causing the interference fringe. If the fixed relation of local phase is destroyed by measurement, the wave function would collapse to another two wave functions $|\psi_1\rangle$ and $|\psi_2\rangle$, and the interference fringe can not be seen.

b. Many Worlds.

This method is almost the same with the above one, except that the wave function is not collapsed to another two, instead, it just split into two parts which are correlated and can be observed statistically, while the wave function as a whole remains. Also, after using the concept of "Einselection" and "Decoherence", it can explain the process of the "split", and the states of the observer are correlated with these branches.

c. Bohmian Mechanics.

This method has described this experiment successfully, although it still has problems with other experiments. Under the combination of the guiding equation and the Schrödinger equation, electrons with different initial coordinates move with distinct path, as Figure 3.2 shows. We should notice that the motion of electron is related to the state of the underlying "field", which is extremely non-classical. The special mathematical derivation is not presented here.

d. Consistent History [12].

Referred to the method of path integral, we introduce the operator S, satisfying $S|mz\rangle = |(m+1)z\rangle$, $m = 0, 1, 2, 3$. As Figure 3.1 shows, $|0\alpha\rangle$,$|1\beta\rangle$,$|1\gamma\rangle$ represent the states of the electron, satisfying

$$\begin{aligned} S|0\alpha\rangle &= \frac{1}{\sqrt{2}}(|1\beta\rangle + |1\gamma\rangle), \\ S|2\beta\rangle &= \frac{1}{\sqrt{2}}(|3a\rangle + |3b\rangle), \\ S|2\gamma\rangle &= \frac{1}{\sqrt{2}}(|3a\rangle - |3b\rangle). \end{aligned} \tag{3.9}$$

We should notice that there are infinite final states, strictly speaking, and also the coefficients, related to the difference between the paths to the slits, are not necessarily equal. Here, we just pick up $|3a\rangle$ and $|3b\rangle$ for clarity.

Also, introduce "phase shifter" S' satisfying

$$\begin{aligned} S'|1\beta\rangle &= e^{i\phi_\beta}|2\beta\rangle, \\ S'|1\gamma\rangle &= e^{i\phi_\gamma}|2\gamma\rangle. \end{aligned} \tag{3.10}$$

Thus, one "framework" ($\mathcal{F}$) is:

$|0\alpha\rangle \to \frac{1}{\sqrt{2}}(|1\beta\rangle+|1\gamma\rangle) \to \frac{1}{\sqrt{2}}(e^{i\phi_\beta}|2\beta\rangle+e^{i\phi_\gamma}|2\gamma\rangle) \to ((e^{i\phi_\beta}+e^{i\phi_\gamma})|3a\rangle+(e^{i\phi_\beta}-e^{i\phi_\gamma})|3b\rangle)/2$.

The probabilities $P(|3a\rangle) = (\cos\phi'/2)^2/4$, and $P(|3b\rangle) = (\sin\phi'/2)^2/4$, where $\phi' = \phi_\beta - \phi_\gamma$. If we destroy the fixed difference ϕ', then the interference fringe disappears.

This method gives a vivid picture, however, it is not the dynamics. And it states that the inherent motion of electron is random, can not be predicted. In addition, it is quite complex to chose a proper $\mathcal{F}$.

e. Decoherence.

In this method, we should describe S and the observer or the apparatus R at the same time, which forms an entangled states. The initial state of the apparatus is $|r\rangle$, the initial state of the system is $|\psi_1\rangle$,$|\psi_2\rangle$. The measurement means $|\psi_1\rangle|r\rangle \to |\psi_1\rangle|1\rangle$, $|\psi_2\rangle|r\rangle \to |\psi_2\rangle|2\rangle$, where $|1\rangle$,$|2\rangle$ is the "pointer state" of the paratus. This is the so-called "pre-measurement", or "C-NOT", von Neumann measurement. When both of the slits are open, the system is superposition state $\psi = \frac{1}{\sqrt{2}}(|\psi_1\rangle + |\psi_2\rangle)$, The measurement means $|\psi\rangle|r\rangle \to \frac{1}{\sqrt{2}}(|\psi_1\rangle|1\rangle + |\psi_2\rangle|2\rangle)$. Introducing the density matrix ρ, which is $\rho = (|\psi_1\rangle\langle\psi_1| + |\psi_2\rangle\langle\psi_2| + |\psi_1\rangle\langle\psi_2|\langle 2|1\rangle + |\psi_2\rangle\langle\psi_1|\langle 1|2\rangle)$. If $\langle 1|2\rangle = 0$, it means the measurement is destructive, the "decoherence" occurs and there is no interference fringe, then we get the particle property. If $\langle 1|2\rangle = 1$, that is $|1\rangle, |2\rangle = |r\rangle$, it means there is no measurement, then we get the wave property. That is to say, the "wave-particle duality" is due to the entanglement and the decoherence.

f. Scope.

Electron satisfies the identity principle, and the ergodic theorem. Interference is a property of a single electron itself, "interfere with itself". In the scope of electron, there are two states $|\psi_1\rangle$, $|\psi_2\rangle$, they interfere with each other. When the electron is send out one by one, till time tends infinity , the electron occupies all the states, full of the scope. When electrons are send out with great mount, the interference fringe can be realized fast. These two ways are equivalent. In order to determine every path of the electron, we can use Bohmian Mechanics for reference, chose the initial coordinate for each electron, introduce the "guiding equation", then we can get the dynamical process.

C. The outline of the interpretations of QM, shown as the table below, where $Q\|C$ means that *classical* is the independent approximation of *quantum*, and

$Q \supset C$ means *classical* is one particular part of *quantum*. For clarity, we use the abbreviation, the specific meanings can be found in Section 3.2.

Table 3.1: The main characters of Quantum Interpretations.

	ψ	$\psi^*\psi$	$\psi \to \psi_i$	Classicality	Method
CI	non-physical	probability	collapse	$Q\|C$	$e-e$ link
MWI	physical	weight	split	$Q \supset C$	$e-e$ link
CHI	non-physical	probability	no-collapse	$Q \supset C$	framework
BM	pilot wave	probability	no-collapse	$Q\|C$	guiding equation
TI	wave	probability	transaction	$Q \supset C$	transaction
PCT	wave packet	probability	collapse	$Q\|C$	localization
EI	non-physical	probability	decoherence	$Q \supset C$	einselection

Bibliography

[1] N. Bohr: *Atomic Theory and the Description of Nature* (Cambridge University Press, Cambridge UK, 22-23, 1961).

[2] W. Heisenberg, *Physics and Philosophy* (George and Unwin, 1958).

[3] W. Heisenberg, *The Physicist's Conception of Nature* (Harcourt, Brace and Company New York, 1958).

[4] J. von Neumann: *Mathematische Grundlagen der Quantnmechanik* (Springer, Berlin 1932), translated as *Mathematical Foundations of Quantum Mechanics* (Princeton University Press, 1955).

[5] H. Everett, *"Relative State" Formulation of Quantum Mechanics*, Rev. Mod. Phys. **29**, 454-462, (1957).

[6] D. Wallace, *Worlds in the Everett Interpretation*, Studies in History and Philosophy of Modern Physics, **33**B(4), 637-661, (2002).

[7] B. S. DeWitt, *The Many-Universes Interpretation of Quantum Mechanics, in Foundations of Quantum Mechanics* (Academic, New York, 1971).

[8] L. de Broglie, *An Introduction to the Study of Wave Mechanics* (E. P. Dutton and Co., New York, 1930).

[9] D. Bohm, *A suggested interpretation of the quantum theory in terms of "hidden variables"*, I and II, Phys. Rev. **85**, 166-193 (1952).

[10] D. Bohm and J. Bub, *A proposed solution of the measurement problem in quantum mechanics by a hidden variable theory*, Rev. Mod. Phys. **38**, 453-469 (1966).

[11] R. B. Griffiths, *Consistent histories and the interpretation of quantum mechanics*, J. Stat. Phys. **36**, 219 (1984);

[12] R. B. Griffiths, *Consistent Quantum Theory* (Cambridge University Press, 2002; and http:// quantum.phys.cmu.edu).

[13] R. Omnés: *Interpretation of quantum mechanics*. Phys. Lett. A **125**, 169 (1987); *Logical reformulation of quantum mechanics* I, II, III. J. Stat. Phys. **53**, 893, 933, 957 (1988).

[14] R. Omnés, *Consistent Interpretations of quantum mechanics*, Rev. Mod. Phys. **64**, 339-382, (1992).

[15] M. Gell-Mann, J. B. Hartle, *Classical equations for quantum systems*, Phys. Rev. D **47**, 3345 (1993).

[16] P. Pearle, *Reduction of the state vector by a nonlinear Schrödinger equation*, Phys. Rev. D **13**, 857-868 (1976).

[17] P. Pearle, *Experimental tests of dynamical state-vector reduction*, Phys. Rev. D **29**, 235-240 (1984).

[18] P. Pearle, *Combining stochastic dynamical state-vector reduction with spontaneous localization*, Phys. Rev. A **39**, 2277-2289 (1989).

[19] N. Gisin, *Quantum measurements and stochastic processes*, Phys. Rev. Lett. **52**, 1657-1660 (1984).

[20] G. C. Ghirardi, A. Rimini, and T. Weber, *Unified Dynamics for Microscopic and Macroscopic Systems*. Phys. Rev. D **34**, 470-91 (1986).

[21] G. J. Milburn, *Intrinsic decoherence in quantum mechanics*, Phys. Rev. A **44**, 5401-5406 (1991).

[22] H. M. Wiseman, *Quantum theory of continuous feedback*, Phys. Rev. A **49**, 2133-2150 (1994).

[23] J. A. Wheeler and R. P. Feynman, *Interaction with the absorber as the mechanism of radiation*, Rev. Mod. Phys. **17**, 157-181 (1945).

[24] J. A. Wheeler and R. P. Feynman, *Classical electrodynamics in terms of direct interparticle action*, Rev. Mod. Phys. **21**, 425-433 (1949).

[25] J. G. Cramer: *The transactional interpretation of quantum mechanics*, Rev. Mod. Phys. **58**, 647-688 (1986).

[26] H. D. Zeh, *On the interpretation of measurement in quantum theory*, Found. Phys. **1**, 69-76 (1970); *Toward a quantum theory of observation*, Found. Phys. **3**, 109-116 (1973).

[27] W. H. Zurek, *Pointer basis of quantum apparatus: Into what mixture does the wave packet collapse?*, Phys. Rev. D **24**, 1516-1525 (1981); *Environment-induced superselection rules*, Phys. Rev. D **26**, 1862-1880 (1982).

[28] W. H. Zurek, *Decoherence, einselection, and the quantum origins of the classical*, Rev. Mod. Phys. **75**, 715-775 (2003).

[29] W. H. Zurek, *Relative states and the environment: Einselection, envariance, quantum Darwinism, and the existential interpretation*, eprint arXiv:0707.2832 [quant-ph].

[30] M. Schlosshauer, *Decoherence, the measurement problem, and interpretations of quantum mechanics*, Rev. Mod. Phys. **76**, 1267-1305 (2004).

[31] B. van Fraassen, *Quantum Mechanics: An Empiricist View* (Clarendon, Oxford, 1991).

[32] D. Dieks, *Modal interpretation of quantum mechanics, measurements, and macroscopic behavior*, Phys. Rev. A **49**, 2290-2300 (1994).

[33] G. Bacciagaluppi, M. Hemmo, *Modal interpretations, decoherence and measurements*, Stud. Hist. Philos. Mod. Phys. **27**, 239-277 (1996).

[34] N. D. Mermin, *The Ithaca interpretation of quantum mechanics*, Pramana **51**, 549-565 (1998).

[35] N. D. Mermin, *What is quantum mechanics trying to tell us?*, Am. J. Phys. **66**, 753-767 (1998).

[36] L. E. Ballentine, *The statistical interpretation of quantum mechanics*, Rev. Mod. Phys. **42**, 358-381 (1970).

[37] A. Einstein, B. Podolsky, N. Rosen, *Can quantum-mechanical description of physical reality be considered complete?*, Phys. Rev. **47**, 777-780 (1935).

[38] J. S. Bell, *On the Einstein - Podolsky - Rosen paradox*, Physics **1**, 195-200 (1964).

[39] J. S. Bell, *On the problem of hidden variables in quantum mechanics*, Rev. Mod. Phys. **38**, 447-452 (1966).

[40] J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics* (Cambridge University Press, Cambridge, England, 1987).

[41] A. Aspect *et al.*, *Experimetal Tests of Bell' s Inequalities Using Time-Varying Analysers*, Phys. Rev. Lett. **49**, 1804-1807 (1982).

[42] N. D. Mermin, *Hidden variables and the two theorems of John Bell*, Rev. Mod. Phys. **65**, 803-815 (1993).

[43] D. Bouwmeester *et al.*, *Experimental quantum teleportation*, Nature, **390**, 575-579 (1997).

[44] Aristotle, *Metaphysics* (Oxford, Clarendon Press, 2006).

[45] H. Margenau, *Advantages and disadvantages of various interpretations of the quantum theory*, Physics Today **7**(10), 6-13 (1954).

[46] A. Shimony, *Experimental test of local hidden variable theories*, in *Foundations of Quantum Mechanics* (B. d' Espagnat ed., Academic, New York, 1971).

[47] I. Prigogine and I. Stengers, *Order out of Chaos* (Bantam Books Inc., 1984).

[48] C. H. Bennett, G. Brassard, S. Popescu, B. Schumacher, J. A. Smolin, and W. K. Wootters, *Purification of Noisy Entanglement and Faithful Teleportation via Noisy Channels*, Phys. Rev. Lett. **76**, 722-725 (1996).

[49] C. H. Bennett, H. J. Bernstein, S. Popescu, and B. Schumacher, *Concentrating partial entanglement by local operations*, Phys. Rev. A **53**, 2046-2052 (1996).

[50] L. D. Landau and M. E. Lifshitz, *Quantum Mechanics, Non-relativistic Theory* (Pergamon Press, 1977).

[51] M. Jammer, *The Philosophy of Quantum Mechanics* (John Wiley, Inc. New York, 1974).

[52] A. G. Kofman and G. Kurizki, Nature, **405**, 546-550 (2000).

[53] D. Dürr, *Bohmsche Mechanik als Grundlage der Quantenmechanik* (Springer, Heidelberg, 2001).

Chapter 4

Nonlocality and Entanglement

In this chapter, we study the two related concepts in QM, Nonlocality and Entanglement. There are lots of studies, both historical and physical in the literature. Though they emerged at the early time of QM, it is only during recent decades that we sense their importance. However, after these years' study, they are not clear yet. Here we try to understand the physical meaning of nonlocality and entanglement.

4.1 Nonlocality

.

The study of Nonlocality originates from the argument of the completeness of QM. The EPR paradox (1935) [1] remained silence until 1952 Bohm [2] formed his famous hidden variable theory (HVT). From this inspiration, Bell generally studied the HVT [3]. Interestingly, the Bell-inequality initially is only one quite small part of Bell's whole research of the foundation of QM. It is the experiment of Aspect which demonstrated the violation of Bell-inequality that stimulates the research of nonlocality [4]. We should notice that at the time, the technique has improved so much that many gedanken experiments and precise measurements beyond ensemble system could be realized. Also, the field of quantum optics was flourishing [5]. There were many "nonlocal" facts of the quantum light, such as anti-bunching, squeezing. The study of nonlocality is in accordance with the study of nonclassicality of light. Now, there are still many studies to use the methods of quantum light to characterize nonlocality [6]. Initially, Bell constructed the inequality to test HVT. However, it turns out that we can not decide whether there exist hidden variable by violation of Bell inequality [7]. Bell inequality is now viewed as a special kind of effective entanglement witness. Generally, we can discuss the theory from three aspects: the hidden variable theory, the bound on the inequality, and the local realism. We would show that nonlocality is not a proper concept for the description of quantum correlations, and Bell inequality is neither a proper detector of quantum correlations.

4.1.1 Hidden Variable Theory

.

It turns out that the constructions of Bell, Bohm, and also de Broglie of HVT are different [8, 9, 10, 11, 12]. Bohm introduced one external parameter, the coordinate, to the equation, which serves as the hidden variable. Every particle has a definite place and path at each time. Bohm mechanics indeed is a kind of "hidden dynamics", not just adding one variable. However, in Bell inequality, the variable λ is only one local external parameter, which does not form any dynamics. In this expression, $\int d\lambda\rho(\lambda)A(\mathbf{a},\lambda)$, λ does not mean anything, no matter the hidden variable is local or non-local [13]. That is to say, the Bell inequality to test the existence of hidden variable is not effective. Hence, a non-violation or even violation of the Bell inequality has nothing to do with HVT. On the contrary, Bohm mechanics still is an effective hidden dynamics beyond the ability of standard QM. From our interpretation based on scope, there indeed is the hidden dynamics.

4.1.2 Bound on the Inequality

.

In the CHSH theory [14], the classical bound is expressed as $|\mathcal{B}_c| \leqslant 2$. Tsirelson proved that for quantum resources and processes, the bound is $|\mathcal{B}_q| \leqslant 2\sqrt{2}$ [15]. Obviously, the non-violation of the classical bound can not determine whether there is nonlocality. Indeed, as has been realized nowadays, these two bounds applies to totally different things, the classical bound $|\mathcal{B}_c|$ apply to classical sources with numbers and the quantum bound $|\mathcal{B}_q|$ applies to quantum sources with operators [16]. The difference demonstrates that the quantum correlation is special relative to the classical correlation. What's more, there could be more nonlocal process, namely, in the PR-box, the bound is $|\mathcal{B}_{PR}| \leqslant 4$ [17]. All the difference on the bounds relates to entanglement. It is recently shown that only quantum dynamics can exhibit entanglement [18]. Thus, it is the entanglement that decides the quantum bound.[1]

4.1.3 Local Realism

.

There are lots of studies on the local realism (LR) of EPR. Many of them agree that quantum mechanics is complete, one of the disagreement is whether QM is local or realistic. There are critics of the local realism [19, 20, 21, 22]. From the

[1] Here we do not intend to study the bound on the inequality in detail. At present, there are many Bell-type inequalities, it needs more efforts to study them well.

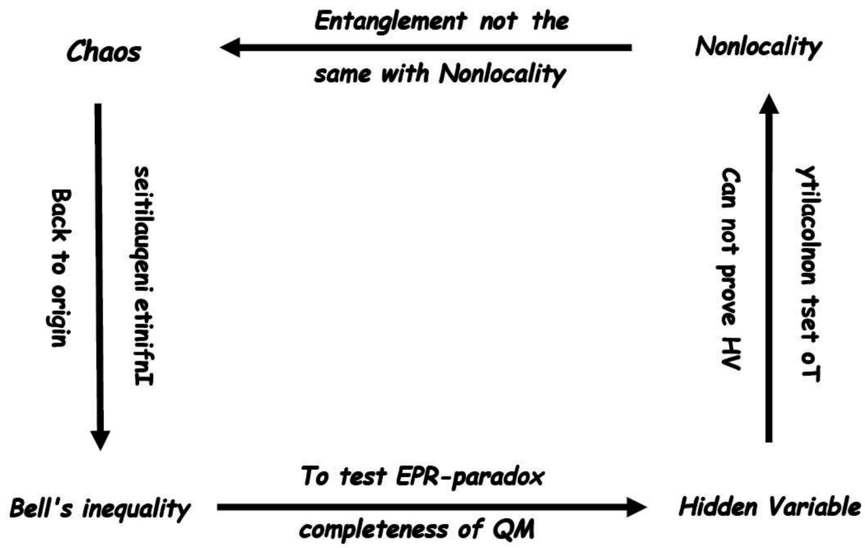


Figure 4.1: The development of Bell's inequality.

view of Scope, we have demonstrated that QM is a kind of systematical description of motion, and LR originates from the classical casual dynamics description. They are different methods, thus they should mainly concern with different problems. So, on the one hand, QM is a kind of nonlocal, non-realism description; on the other hand, the hidden casual description is indeed local and realism. Thus, confusion of LR is only fictive. In the appendix, we give a new interpretation of the original argument of EPR-paper.

In conclusion, the Bell inequality is originally to characterize hidden variable. After the failure, it is used to mark the existence of nonlocality. Then, it turns out some entangled states still obey the Bell inequality, and the concept of nonlocality is thus not the same with entanglement [23, 24, 25]. At present, there are still lots of Bell type inequalities, such as the CGLMP, the MABK, the CFRD inequalities [26, 27, 28, 29, 30]. In principle, there could be infinite kinds of inequalities. One reason the Bell inequality as the entanglement detector is that it is easy to realize in experiment, since it is designed for experiment directly. However, there exist other more reliable methods to study entanglement by experimental means, namely, the GHZ theorem without inequality [31, 32, 33]. It is the "all versus nothing" method to determine the existence of entanglement.

The situation of Bell theory can be depicted as Figure 4.1.

The most effective and powerful way to detect quantum correlation is to study it directly. The Bell inequality can be viewed as a kind of indirect method. The terminology "nonlocality" and "contextuality" cause pretty much chaos, for instance, we can not even set a border between nonlocality and locality. These terminologies sound more philosophical than physical. Due to our interpretation based on *scope*, the reason for the origin of HVT, EPR-paradox, and Bell's inequality are the confusion of the method of QM. In addition, in quantum field and quantum cosmology theory, "local" and "global" are also used in the literature, however, the meaning is different with "nonlocality" generally. Since the scale of the field, such as the gravity field, is large, and field is a coherent entity, the meaning of local and global is quite clear (as in geometry).

4.2 Entanglement

.

After abandoning the method of nonlocality, we should focus on the study of entanglement. However, due to present theory, entanglement is neither defined directly. Entanglement is defined according to state, and it is defined negatively, that is, we define the states which are not entangled. For the definition of entanglement, we can classify two aspects: the detector of entanglement and the degree of entanglement. At present, there are dozens of methods, such as the PPT criterion [34] and the negativity [35], the entanglement of formation [36] and concurrence [37, 38], the distillable entanglement [39], the entanglement cost [40], and the bound entanglement [41, 42, 43], the entanglement witness [44, 45, 46] and witnessed entanglement [47], the entropy measure [48], the uncertainty measure [49, 50, 51, 52, 53, 54, 55, 56, 57, 58], the geometry measure [59], the robustness [60, 61], the cross/realignment [62, 63], the covariance matrix criteria [64, 65], etc.. After all, we still can not answer the question quickly: given a state ρ, whether it is entangled, or not?

At present, the definitions of entanglement, as listed above, are either mathematical or operational. This may be due to that the theory of quantum entanglement originates from the field of quantum information and quantum computation (QIQC). It is well known that QIQC is the application of quantum entanglement, that is to say, entanglement not only is useful in QIQC. For instance, even earlier, entanglement is very important to the theory of the formation of molecule in quantum chemistry. Below, we study entanglement physically from four aspects. Firstly, the classification of quantum state. Secondly, the definition of degree of superposition ε and entanglement E, and the relations to other entanglement detectors. Thirdly, the decoherence process. Forth, the principle of the coherence of the universe.

4.2.1 Classification of the Quantum State

.

At present, there is no unified classification of quantum states. Briefly, there are many kinds due to different criterions, such as separable/entangled, pure/mixed, local/non-local, etc.. As we have discussed, we do not think nonlocality is a good

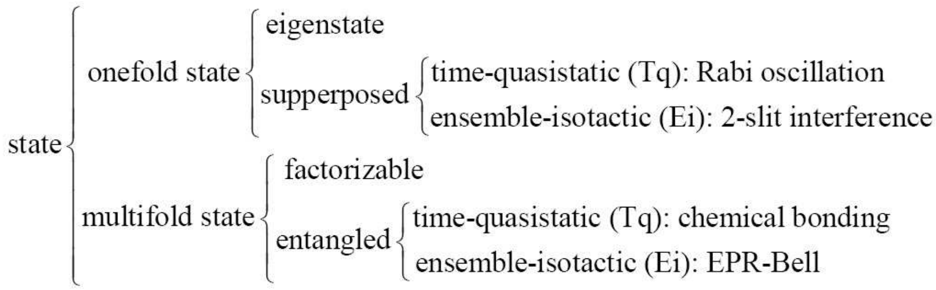


Figure 4.2: The classification of quantum state.

way to characterize the state, even we can not distinguish non-local from local. The first division, separable/entangled, relies on the mathematical definition of entangled state, the physical meaning is not very clear. The second division borrows the idea from thermodynamics. A mixed state is a mixture of pure states. Also, mixed state can also be viewed as the inner party of one bigger pure state after tracing out the rest part. Strictly speaking, "mixed state" is a classical concept, it is not accurate to describe the coherence.

We can classify the state as Figure 4.2 shows. The classification is explained as follows. Firstly, state is divided according to whether it is a multifold state. For a single system, its state is onefold state. There can be superposed state. For multifold system which contains several inner parts, the state is multifold state, there can be entangled state. The division of time-quasistatic (Tq) state and ensemble-isotactic (Ei) state bases on the theorem of ergodicity of statistical physics and the identity principle of QM.

For example, the double-slit state of the electron (or other particles) is the Ei state, which characterizes the electron ensemble. In this state, for one particular electron, it can only pass through one slit at one time, thus, the state of a single electron is not superposed. Another example, we can use laser to control a certain two-level atom, and drive it to the so-called Rabi oscillation [66]. This is the Tq state, the population transfers from one state to another periodically. The famous Bell basis are the Ei entangled state, such as the light source from type-II SPDC [67] in the teleportation experiment, describing the ensemble of photons, the state of one photon is not entangled or superposed. An excellent example of Tq entangled state is the electrons forming the chemical bonding in the molecules. We state that there should be and will be other examples to support this classification.

The difference between (Ei) state and (Tq) state is the "inner" dynamics of the state itself, thus, this kind of definition is obviously not mathematical.[2]

[2]However, in our study below, we do not care about this difference without losing of generality.

4.2.2 Degree of Superposition ε and Entanglement $\mathcal{E}$

.

A proper word to describe the situation of the research of entanglement at present should be "complex". For clarity and simplicity, we may present our interpretations of entanglement from four aspects: the basic observation, the qualitative study, the quantitative study: pure state case, the quantitative study: mixed state case.

Basic observation. In this part, we make some comments on the detectors based on inequalities. At present, inequality is used as one method to decide the existence of nonclassical correlation, which could not be violated by classical correlation. The most famous one is the Bell inequality. When it is violated, there must be nonlocality or entanglement, while it is not violated, there still could be entanglement. Thus, it is not a trustworthy but valuable detector. Secondly, the positive partial transpose (PPT) and positive map. The PPT criteria is only necessary and sufficient for $2 \otimes 2$ and $2 \otimes 3$ systems, it can not detect the "bound entanglement" [41]. Thirdly, the covariance matrix criterion (CMC). Recently, Gittsovich *et. al.* used CMC to unify several detectors, such as the computable cross norm/realignment (CCNR). Forth, the CCNR. Particularly, Rudolph set the relation between CCNR and robustness [62].[3] Fifth, the uncertainty relation (UR) [49, 50, 51, 52, 53, 54, 56, 57, 58]. One kind is the entropic UR [50, 51, 52, 53], another one is the local UR [54, 55], which could detect bound entanglement. Sixth, the entanglement witness. Recently, Brandão set the quantity "witnessed entanglement" [47], and took a unified view of the negativity, maximal fidelity, concurrence, robustness, the best separable approximation detectors. Also, nonlinear entanglement witness is constructed to improve the bound of the inequalities [45, 46]. In addition, there also exist other detectors which we do not list here.

In principle, there could be many inequalities based on different mathematical properties. However, the nonclassical correlations (NCC) detected by them could be different, physically. That is, there is no unique definition of entanglement.

Qualitative study. Below we try to study the physical essence of NCC. There are three points we have to state before our study. First, the method "nonlocality" is not adopted. Second, the method "discord" is employed [68, 69, 70], which is found recently, although there are different definitions. Third, in order to describe quantum state schematically, we use the method "infornet" (information-net, the method we discuss below). Also, there are other methods to describe the geometric properties of a state [71, 72], we do not intend to study this issue in detail here.

Suppose, there is a two-party (A and B) entangled state (ES), each has three states, shown in Figure 4.3 (a), the relative states sit on the infornet. There are three characters in this ES. Firstly, according to the "1-1 branch principle" (Chapter 2), one state of A and one state of B together form one branch, there are

[3] Also, Vidal and Werner set the relation between negativity and robustness [35].

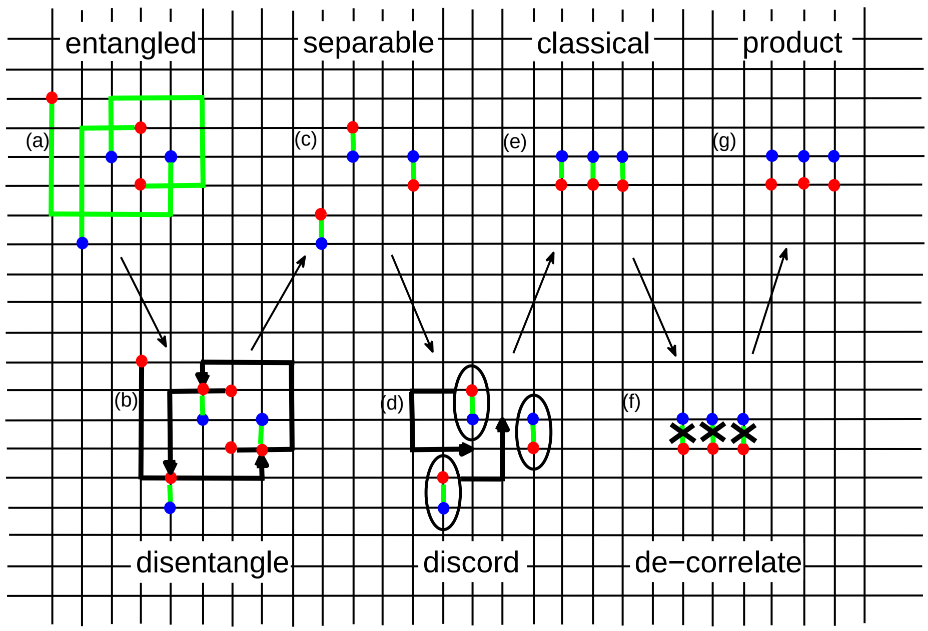


Figure 4.3: The 2-dimensional schematic of the dynamics of non-classical correlation on the infornet. Blue (red) points are the states of A (B), green lines are the strings within the branches. Panel (a): the entangled state (ES); Panel (b): the disentangle process, the black arrows represent the process, the state each moves along the string; Panel (c): the separable state; Panel (d): the discord process, the black arrows represent the process, the branch moves along the line of the infornet; Panel (e): the classical state; Panel (f): the de-correlate process, the black crosses represent the process; Panel (g): the product state.

totally three branches. Secondly, there is one line or "string" within each branch, and there is only one "crossing point" between two branches, there are totally three crossing points. Thirdly, the ES has a certain structure with symmetry. So, this kind of structure is inseparable.[4]

When disentangle occurs, the relative states move along their strings, so that the crossing points disappear. In panel (b), we give a sketch of the disentangle process, we let the states of B move, and the states of A stay. Then, we get the separable state, shown in panel (c). In separable state, there could still be nonclassical correlation: the three branches have different sits and orientations, that is, if we want to get information, we have to disturb the state [68].

There has to be a discord process until the state becomes classical totally. During discord, shown in panel (d), the branches move till they have the same orientations, as in panel (e). The states of A sit along a line, and states of B sit along another nearby line, and, there are still correlations between them. If this classical correlations are get rid of by a "de-correlate" process, we finally get the product state, panel (g).

In all, if we start from the product state, in order to get the ES, the first step needed is to correlate the relative states of A with B one to one, then the branches move and form strings, and then form the steady entangled structure.

In addition, the discord process may not be needed. If after the disentangle process, the branches have the regular and simplest arrangement, then the discord process is already realized. And, for another thing, the decoherence process means the process from the ES to the classical state, that is, the disentangle process and the discord process (from panel (a) to (e)).

Quantitative study: pure state. In the above, we give a qualitative study of the non-classical correlation (NCC). We should demonstrate that the classical correlation comes from the NCC, it is the "residual" NCC, that is, it is the "classical limit" of the NCC.[5]

Next, we study entanglement quantitatively.

Definition 1. Degree of superposition of state ε.
For a superposed state vector $|\Psi\rangle = \sum_i^n a_i|\psi_i\rangle$, where $\sum_i^n |a_i|^2 = 1$, $\langle\psi_i|\psi_j\rangle = 0$, the degree of superposition

$$\varepsilon \equiv \sum_{i<j}^{n} |a_i||a_j|. \tag{4.1}$$

Notice that, introduce the l_2-norm as $||a||_{l_2}= \sum_i^n |a_i|^2$, then the l_1-norm is $||a||_{l_1}= \sum_i^n |a_i|$, thus $\varepsilon = \frac{1}{2}(||a||_{l_1}^2 - ||a||_{l_2})$.

[4]In addition, we should state again this description is not exact.

[5]This statement is in accordance with that the classical is only a special part of the quantum world, in fact, there exists only one world (see Chapter 3).

For example, $n = 1$, $\varepsilon = 0$. $n = 2$, $|\Psi\rangle = a_1|\psi_1\rangle + a_2|\psi_2\rangle$, $\varepsilon = |a_1a_2|$, and Max(ε)= 1/2 when $|a_1| = |a_2| = 1/\sqrt{2}$. $n = 3$, $|\Psi\rangle = a_1|\psi_1\rangle + a_2|\psi_2\rangle + a_3|\psi_3\rangle$, $\varepsilon = |a_1a_2| + |a_2a_3| + |a_1a_3|$, and Max($\varepsilon$)= 1 when $|a_1| = |a_2| = |a_3| = 1/\sqrt{3}$. Then generally, for $n = 4, 5, ...$, Max(ε)= $3/2, 2, ...$ etc.. That is, for n, the maximal degree of superposition ε is $\frac{n-1}{2}$, and the minimum approaches to *zero*. If there are more eignstates in a superposed state, then the degree of superposition it can get is bigger. It means, physically, that although a state vector in the Hilbert space has to be normalized, the degree of superposition is not a relative quantity, its magnitude has physical meaning.

Definition 2. Degree of entanglement of states $\mathcal{E}$.
For a general entangled state with m subsystems $n \otimes n \otimes ... \otimes n$ with each n-dimensional: $|\Psi\rangle = \sum_i^n c_i|\psi_{1i}\psi_{2i}...\psi_{mi}\rangle$, the degree of entanglement

$$\mathcal{E} \equiv \sum_{i<j}^{n} |c_i||c_j|. \tag{4.2}$$

The same with the degree of superposition, we can get $\mathcal{E} = \frac{1}{2}(||c||_{l_1}^2 - ||c||_{l_2})$.

Next we study some fundamental applications.

For $2 \otimes 2$ system, the Bell diagonal state, if

$$\begin{aligned} |\Psi_A\rangle &= a_1|\psi_1\rangle + a_2|\psi_2\rangle, \varepsilon_A = a_1a_2, \\ |\Psi_B\rangle &= b_1|\psi_1\rangle + b_2|\psi_2\rangle, \varepsilon_B = b_1b_2. \end{aligned} \tag{4.3}$$

We assume the coefficients are all positive, without losing of generality. Let $|\psi_1\rangle = |1\rangle$, $|\psi_2\rangle = |2\rangle$.

There are two kinds of ES, symmetrical and asymmetrical:

$$\begin{aligned} |\Psi_s\rangle &= \frac{a_1b_1|11\rangle + a_2b_2|22\rangle}{\sqrt{a_1^2b_1^2 + a_2^2b_2^2}}, \\ |\Psi_a\rangle &= \frac{a_1b_2|12\rangle + a_2b_1|21\rangle}{\sqrt{a_1^2b_2^2 + a_2^2b_1^2}}, \end{aligned} \tag{4.4}$$

and the degree of entanglement

$$\begin{aligned} \mathcal{E}_s &= \frac{a_1a_2b_1b_2}{a_1^2b_1^2 + a_2^2b_2^2}, \\ \mathcal{E}_a &= \frac{a_1a_2b_1b_2}{a_1^2b_2^2 + a_2^2b_1^2}, \end{aligned} \tag{4.5}$$

generally, $\mathcal{E}_s \neq \mathcal{E}_a$.

After some algebra, we can get

$$\frac{\varepsilon_A\varepsilon_B}{\mathcal{E}_s}+\frac{\varepsilon_A\varepsilon_B}{\mathcal{E}_a}=1. \tag{4.6}$$

Introduce the reduced degree of entanglement $\mathcal{E}^\dagger=\frac{\mathcal{E}_s\mathcal{E}_a}{\mathcal{E}_s+\mathcal{E}_a}$, then we can get the fundamental relation

$$\mathcal{E}^\dagger=\varepsilon_A\varepsilon_B. \tag{4.7}$$

When $a_1=a_2=b_1=b_2=\sqrt{2}/2$, $\varepsilon_A=\varepsilon_B=1/2$, $|\Psi_s\rangle=\frac{\sqrt{2}}{2}(|11\rangle+|22\rangle)$, $|\Psi_a\rangle=\frac{\sqrt{2}}{2}(|12\rangle+|21\rangle)$, $\mathcal{E}_s=\mathcal{E}_a=1/2$, and $\mathcal{E}^\dagger=1/4$. This is the maximal condition for the Bell diagonal state.

For $2\otimes2\otimes2$ system, if

$$\begin{aligned}|\Psi_A\rangle &= a_1|\psi_1\rangle+a_2|\psi_2\rangle, \varepsilon_A=a_1a_2,\\ |\Psi_B\rangle &= b_1|\psi_1\rangle+b_2|\psi_2\rangle, \varepsilon_B=b_1b_2,\\ |\Psi_C\rangle &= c_1|\psi_1\rangle+c_2|\psi_2\rangle, \varepsilon_C=c_1c_2.\end{aligned} \tag{4.8}$$

There are four kinds of ES, which belongs to the GHZ state:

$$\begin{aligned}|\Psi^1_{GHZ}\rangle &= \frac{a_1b_1c_1|111\rangle+a_2b_2c_2|222\rangle}{\sqrt{a_1^2b_1^2c_1^2+a_2^2b_2^2c_2^2}},\\ |\Psi^2_{GHZ}\rangle &= \frac{a_1b_1c_2|112\rangle+a_2b_2c_1|221\rangle}{\sqrt{a_1^2b_1^2c_2^2+a_2^2b_2^2c_1^2}},\\ |\Psi^3_{GHZ}\rangle &= \frac{a_2b_1c_1|211\rangle+a_1b_2c_2|122\rangle}{\sqrt{a_2^2b_1^2c_1^2+a_1^2b_2^2c_2^2}},\\ |\Psi^4_{GHZ}\rangle &= \frac{a_1b_2c_1|121\rangle+a_2b_1c_2|212\rangle}{\sqrt{a_1^2b_2^2c_1^2+a_2^2b_1^2c_2^2}},\end{aligned} \tag{4.9}$$

and it is easy to write the four degree of entanglement (we do not present here), after some algebra, we get

$$\frac{\varepsilon_A\varepsilon_B\varepsilon_C}{\mathcal{E}_1}+\frac{\varepsilon_A\varepsilon_B\varepsilon_C}{\mathcal{E}_2}+\frac{\varepsilon_A\varepsilon_B\varepsilon_C}{\mathcal{E}_3}+\frac{\varepsilon_A\varepsilon_B\varepsilon_C}{\mathcal{E}_4}=1. \tag{4.10}$$

Also, introduce the reduced degree of entanglement $\mathcal{E}^\dagger=\frac{\mathcal{E}_1\mathcal{E}_2\mathcal{E}_3\mathcal{E}_4}{\mathcal{E}_1\mathcal{E}_2\mathcal{E}_3+\mathcal{E}_1\mathcal{E}_2\mathcal{E}_4+\mathcal{E}_1\mathcal{E}_3\mathcal{E}_4+\mathcal{E}_2\mathcal{E}_3\mathcal{E}_4}$, then

$$\mathcal{E}^\dagger=\varepsilon_A\varepsilon_B\varepsilon_C. \tag{4.11}$$

For the maximal condition, when all the coefficients equal to $\sqrt{3}/3$, $\varepsilon_A=\varepsilon_B=\varepsilon_C=1/2$, $\mathcal{E}_1=\mathcal{E}_2=\mathcal{E}_3=\mathcal{E}_4=1/2$, and $\mathcal{E}^\dagger=1/8$.

Generally, for $2\otimes^n$ system, the maximal reduced entanglement is $\mathcal{E}^\dagger=1/2^n$. This means when we add the numbers of systems to be entangled, the reduced entanglement becomes smaller and smaller, that is, the entanglement of the whole system becomes more fragile, when one subsystem is disturbed, the total entanglement vanishes.

For $3 \otimes 3$ system, if

$$\begin{aligned} |\Psi_A\rangle &= a_1|\psi_1\rangle + a_2|\psi_2\rangle + a_3|\psi_3\rangle, \varepsilon_A = a_1a_2 + a_2a_3 + a_1a_3, \\ |\Psi_B\rangle &= b_1|\psi_1\rangle + b_2|\psi_2\rangle + b_3|\psi_3\rangle, \varepsilon_B = b_1b_2 + b_2b_3 + b_1b_3. \end{aligned} \tag{4.12}$$

There are six kinds of ES according to the symmetry between the branches within the ES. Here we only give two examples, the other four are easy to be drawn:

$$\begin{aligned} |\Psi_1\rangle &= \frac{a_1b_1|11\rangle + a_2b_2|22\rangle + a_3b_3|33\rangle}{\sqrt{a_1^2b_1^2 + a_2^2b_2^2 + a_3^2b_3^2}}, \\ |\Psi_2\rangle &= \frac{a_1b_2|12\rangle + a_2b_1|21\rangle + a_3b_3|33\rangle}{\sqrt{a_1^2b_2^2 + a_2^2b_1^2 + a_3^2b_3^2}}. \end{aligned} \tag{4.13}$$

The entanglements of these six states have the form $\mathcal{E}_i = \alpha_i/\beta_i$. After some algebra, we can get

$$\begin{aligned} \sum_i^6 \frac{\alpha_i}{\mathcal{E}_i} &= \sum_i^6 \beta_i = 1, \\ \sum_i^6 \alpha_i &= 2\varepsilon_A\varepsilon_B. \end{aligned} \tag{4.14}$$

For the maximal condition, when $\alpha_i = 1/3$, $\beta_i = 1/3$, $\varepsilon_A = \varepsilon_B = 1$, $\mathcal{E}_i = 1$. For this 2-qutrit ES, there is no definite form of reduced entanglement.

For $4 \otimes 4$ system, there exist totally twenty-four different ES, each has four branches. The entanglement also can be written as $\mathcal{E}_i = \alpha_i/\beta_i, i = 1, 2, ...24$. We get the following equations

$$\begin{aligned} \sum_i^{24} \frac{\alpha_i}{\mathcal{E}_i} &= \sum_i^{24} \beta_i = 6, \\ \sum_i^{24} \alpha_i &= 4\varepsilon_A\varepsilon_B. \end{aligned} \tag{4.15}$$

For the maximal condition, when $\alpha_i = 3/8$, $\beta_i = 1/4$, $\varepsilon_A = \varepsilon_B = 3/2$, $\mathcal{E}_i = 3/2$.

Generally, for $n \otimes n$ system, there are $N = n!$ different ES, set $\mathcal{E}_i = \alpha_i/\beta_i$, we can get the general equations as

$$\sum_i^N \frac{\alpha_i}{\mathcal{E}_i} = \sum_i^N \beta_i = (n-1)!, \tag{4.16}$$
$$\sum_i^N \alpha_i = 2(n-2)!\varepsilon_A \varepsilon_B.$$

For the maximal condition, when $\alpha_i = (n-1)/2n$, $\beta_i = 1/n$, $\varepsilon_A = \varepsilon_B = (n-1)/2$, $\mathcal{E}_i = (n-1)/2$. That is, for the two-party systems, when the number of states entangled together increases, the Max($\mathcal{E}$) also increases, like the superposition ε. This is reasonable since when more states are entangled together, the amount of entanglement should increase, and the ES becomes more robust.

However, for the higher dimensional systems, the math is too complex, and the physical picture is not easy to imagine. This is an open problem not resolved.

Next, we study the comparison with other measures of entanglement.

(1). Bell states. Concurrence is $\mathcal{C} = 1$. Negativity is $\mathcal{N} = 1/2$. Robustness is $\mathcal{R} = 1$. Entanglement of entropy is $E_S = 1$. Relative entropy is $E_r = 1$. Entanglement is $\mathcal{E} = 1/2$, reduced entanglement is $\mathcal{E}^\dagger = 1/4$.

(2). GHZ state $|\psi\rangle^n = \frac{1}{\sqrt{2}}(|0\rangle^{\otimes n} \pm |1\rangle^{\otimes n})$. For $n = 3$, three-tangle is $\tau_3 = 1$. Negativity is $\mathcal{N} = 1/2$. Robustness is $\mathcal{R} = 1$. Entanglement of entropy is $E_S = 1$. Relative entropy is $E_r = 1$. Entanglement is $\mathcal{E} = 1/2$, reduced entanglement is $\mathcal{E}^\dagger = 1/2^n$ (for general n).

(3). W state $|\psi_W\rangle = \frac{1}{\sqrt{3}}(|001\rangle + |010\rangle + |100\rangle)$. Three-tangle is $\tau_3 = 0$. Negativity is $\mathcal{N} = 2\sqrt{2}/3$. Robustness is $\mathcal{R} = 1$. Entanglement of entropy is $E_S = 1$. Relative entropy is $E_r = \log_2 9/4$.

Particularly, the W state does not satisfy the "1-1 branch principle". There also exists the so-called anti-W state $|\psi_{W'}\rangle = \frac{1}{\sqrt{3}}(|110\rangle + |101\rangle + |011\rangle)$. In fact, W and W′ come from the re-combination of three GHZ-type states $|\psi_1\rangle = \frac{1}{\sqrt{2}}(|001\rangle + |110\rangle)$, $|\psi_2\rangle = \frac{1}{\sqrt{2}}(|010\rangle + |101\rangle)$, $|\psi_3\rangle = \frac{1}{\sqrt{2}}(|100\rangle + |011\rangle)$. The entanglement of $|\psi_1\rangle$, $|\psi_2\rangle$, and $|\psi_3\rangle$, transfer to $|\psi_W\rangle$ and $|\psi_{W'}\rangle$, the total entanglement is conserved. That is $\mathcal{E}_{\psi_1} + \mathcal{E}_{\psi_2} + \mathcal{E}_{\psi_3} = \mathcal{E}_W + \mathcal{E}_{W'}$. Since $\mathcal{E}_{\psi_i} = 1/2$, we get $\mathcal{E}_W = \mathcal{E}_{W'} = 3/4$.

Also, we can calculate in another way. There only exist bi-party entanglement, labeled as $\mathcal{E}_2$, in $|\psi_W\rangle$, there is no three-tangle since the W state breaks it, thus $\mathcal{E}_W = (3\mathcal{E}_2)/2 = 3/4$, here entanglement should be divided by two since every bi-party entanglement is counted twice.

So, we can conclude there are more entanglement in W state than GHZ state, $\mathcal{E}_W > \mathcal{E}_{GHZ}$.

Quantitative study: mixed state. At present, there are two views of mixed state (MS). Firstly, according to thermodynamics (TD), a mixture is the ensemble of many systems, there may be classical correlations among them. However, as we have discussed, it can not reveal the coherent correlation. Secondly, according to

QM, a mixed state should be viewed as an inner part of a global pure state. Thus, a mixed state is only a fragment, not a complete state. However, it is quite hard to construct the global pure state according to the mixed state, also, it is hard to quantify entanglement in this way.

At present, there are mainly three ways to detect entanglement of MS (EMS). Firstly, the "self" method, that is, to detect EMS based on the property of the density matrix ρ itself, such as the PPT-criteria [34], the concurrence [38]. Secondly, the "inside" method, that is, to detect EMS based on the inner property, such as decomposition of ρ. The entanglement of formation is defined as the average entanglement of the pure states of decomposition, minimized over all decompositions of ρ [39]. Another one is the best separable approximation (BSA) based on the Lewenstein-Sanpera (LS) decomposition [73]. It states that ρ in $\mathcal{C}^2 \otimes \mathcal{C}^2$ has a unique decomposition $\rho = \lambda\rho_s + (1-\lambda)|\psi_e\rangle\langle\psi_e|$, λ is maximal, the entanglement is defined as $\mathcal{E}(\rho) = (1-\lambda)\mathcal{E}(|\psi_e\rangle)$. Thirdly, the "outside" method, that is, to view ρ as a whole, and employ other density matrix, such as the geometry measure (GM) [59], the robustness [60]. GM defines the entanglement as the distance or angle between ρ and its nearest separable state. Robustness is defined as the minimal amount of separable noise needed to destroy the entanglement of ρ.

We should note that we do not include the operational methods, such as distillable entanglement, and the operator-based methods, such as the witness.

We can see that there is no unique way to describe the EMS, the reason is that it is not a complete state, and what is lost and how it is lost are unknown. However, there should be a minimal separable set to complete the mixed state, and the entanglement of the resulted global pure state equals to the entanglement of ρ. However, this is left to be an open problem.

Another issue related to mixed state is entropy. Entropy $\mathcal{S}$ describes the "order" of a certain mixture. Also, entropy is used to characterize information. In quantum information, the entanglement of entropy, the relative entropy, and the entropic uncertainty relations are used to detect entanglement. So, physically, are entropy $\mathcal{S}$ and entanglement $\mathcal{E}$ the same? The answer should be *No*. For example, for a classical mixture, that is the entanglement is zero, however, the negentropy could be maximal. On the contrary, if entanglement is maximal, that is there exist NCC, the negentropy could also be maximal. Generally, entropy can describe the degree of both classical and nonclassical "order". Further, the two methods "order" and "correlation" are different, the former one mainly cares about the global properties of the system, while the later one mainly cares about the relational properties of the parts of the system.[6] Thus, it is not physically proper to use entropy to describe entanglement. On the contrary, both of them can be used to describe information.

[6]Of course, they connect with each other.

4.2.3 Decoherence

.

The theory of decoherence has achieved a lot in these years. At the early time, Zeh [74] demonstrated the "openness" of quantum system and the measurement process. Zurek [75] found that there exists "preferred basis" problem laying out of the range of orthodox interpretation. He demonstrated the importance of environment, and uses the so called "environment induced selection (enselection)" to determine the pointer state and the preferred basis. Further, Zurek termed "envariance" to derive the Born's rule based on entanglement [76, 77]. However, the decoherence approach has not totally solved the measurement problem: it can not tell the definite outcome of each measurement [78, **?**]. Below, we study the measurement problem from a new point of view.

We start from the well-known von Neumann measurement. For the two-party measurement problem, the process is expressed as

$$|\psi_S\rangle|\psi_A\rangle = (\sum_i^N a_i|S_i\rangle)|\psi_A\rangle \rightarrow \sum_i^N a_i|S_i\rangle|A_i\rangle, \tag{4.17}$$

thus, form the entangled state. Actually, the outcome is not selected, that is, the measurement is not completed. For this reason, the von Neumann measurement is often called the "pre-measurement" [79].

By introducing decoherence, Zurek modified the von Neumann measurement approach [76]. The expression of the wave function of the combined system is a Schmidt decomposition. However, there should be in principle infinite ways to decompose the wave function, so there exists the "preferred basis" problem. Zurek uses one additional system E to perform one pre-measurement on A to diminish the basis ambiguity, as follows:

$$(\sum_i^N a_i|S_i\rangle)|\psi_A\rangle|\psi_E\rangle \rightarrow \sum_i^N a_i|S_i\rangle|A_i\rangle|\psi_E\rangle \rightarrow \sum_i^N a_i|S_i\rangle|A_i\rangle|E_i\rangle. \tag{4.18}$$

After tracing out the $|\psi_E\rangle$, the state $|\psi_{SA}\rangle$ is

$$\rho_{SA} = \sum_i^N |a_i|^2|S_i\rangle\langle S_i||A_i\rangle\langle A_i|, \tag{4.19}$$

when $\langle E_i|E_j\rangle \equiv 0$.

Also, Zurek uses the symmetry of entangled state, "envariance", to derive the Born's rule, however, the approach has the problem of "argue in a circle" [80].

Although much help with the process of decoherence, the measurement problem is not resolved totally. Next we present a new approach to the measurement problem.

Firstly, the von Neumann pre-measurement can be re-interpreted. If the measurement can be performed, the branches of the entangled state can be formed according to the combination of $|S_i\rangle$ and $|A_i\rangle$, and the underlying coherence between $|\psi_S\rangle$ and $|\psi_A\rangle$ can be realized. There are i (i=1, 2,...N) branches in the entangled state. When $i = 1$, the state is separable. When we carry out the measurement, we have to choose one certain representation to determine which observable we want to detect (or to select, or singlet out). For example, if we want to measure the energy E, thus, the preferred basis of the system is the eignstates of E, also the eignstates of the apparatus are the eignstates of E. There is no need to determine which basis is the most robust preferred basis, since physically there is no other basis. When we want to measure in another representation, we get another preferred basis. These two sets of basis can transform into each other with unitary operator, however, this transformation only has mathematical meaning, the corresponding physical processes are totally different. The point is the two kinds of measurements are non-commute, the same as the observable. That is, the non-commute measurements cannot be carried out at the same time. Every kind of measurement is not "complete", it can only select out a particular kind of outcomes[7]. Further, for the outcome, we can determine the state $|S_i\rangle$ according to the state $|A_i\rangle$, thus, we can predict the definite outcome of one certain measurement of the observable O as $\langle S_i|O|S_i\rangle$, as long as we can determine the state $|A_i\rangle$. However, it seems impossible for us to know the information of $|S_i\rangle$ or $|A_i\rangle$. The reason may be that quantum mechanics views every state $|A_i\rangle$ the "same" (or isotactic) with each other except their coefficient a_i[8].

Next we form a "bi-environment approach" for further understanding. The system S has an environment S', and the apparatus A also has an environment A'[9]. The four-party entanglement process is

$$\begin{aligned} (|\psi_S\rangle|\psi'_S\rangle)(|\psi_A\rangle|\psi'_A\rangle) &= (\sum_i^N a_i|S_i\rangle|S'_i\rangle)(\sum_i^N b_i|A_i\rangle|A'_i\rangle) \\ &\rightarrow (\sum_i^N c_i|S_i\rangle|A_i\rangle)(\sum_i^N d_i|S'_i\rangle|A'_i\rangle), \end{aligned} \tag{4.20}$$

where a_i, b_i, c_i, d_i are coefficients to maintain normalization. If we ignore the environments S' and A', the results reduce to the original von Neumann approach. When tracing out the environment S' and A', and the apparatus A, we get the statistical results of the system S. This is indeed the same as entanglement swap-

[7]Every particular set of outcomes should be called "classical", and these different "classical worlds" together form the "quantum world". However, the relation between "classical" and "quantum" is not the subject in this note.

[8]The further reason should be the lack of dynamics of quantum mechanics, such as the Bohm mechanics [2].

[9]Generally, for every system, there exists at least one environment.

ping (or transfer) between two entangled states [81, 82], which can be expressed as

$$\mathcal{E}(SS') + \mathcal{E}(AA') \rightarrow \mathcal{E}(SA) + \mathcal{E}(S'A'), \tag{4.21}$$

the total entanglement is conserved.

From this bi-environment approach, we can learn the importance of measurement and environment. Firstly, the openness of the quantum system indeed means the connection with environment by information. Decoherence is indeed the information process as Zurek demonstrated [76]. Secondly, this approach is quite the same as the original von Neumann approach, except that here we include the necessary environment, and demonstrate the importance of environment, information, entanglement, and decoherence. Thirdly, the measurements are also operator, so they also obey the commutation relation, the same as observable. Every measurement needs one special representation, and can only get part of the properties of the system. And what is more, it is not resonable to only introduce one environment to solve the preferred basis problem. In fact, by this environment, the entanglement between $|\psi_S\rangle$ and $|\psi_A\rangle$ is improperly changed, from two-party to three-party, thus this approach should not be proper.

4.2.4 The Principle of the Coherence of the Universe (PCU)

.

From the above study, we can see the importance of information and entanglement, which has never been demonstrated by other principles before in physics. Thus, there may be a certain new principle unknown, namely, the principle of the coherence of the universe expressed as

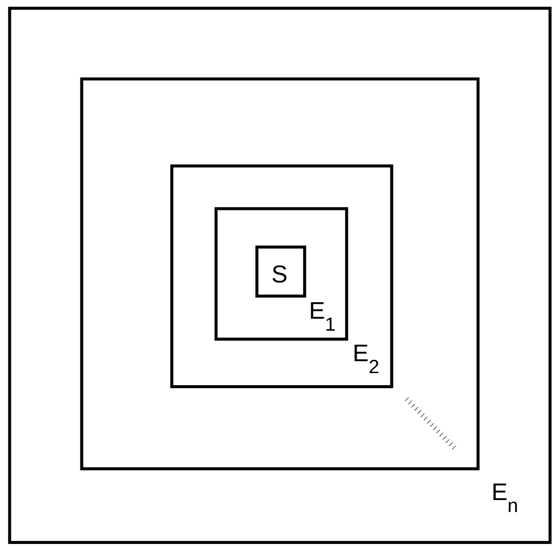
The universe is a coherent entity not only by mass, energy, but also by information.

This principle demonstrates the importance of information. Here, we interpret information as coherent, including the classical case. We assume that the universe U can be viewed as a whole, and it can be divided into system S and environment E, $U = S + E$. This division is possible, and can be performed by our human beings. Then between S and E, there exist coherence and entanglement, this amount of information is selected by our observation, in the sense that if we do not divide the U, we can never know the coherence.[10] When we only care about the system and discard the E, we would find the decohered statistical system. This is easy to understand. The coherence is distributed in $S + E$, when we discard

[10] The similar kind of interpretation is also well studied by Wheeler by "it from bit": "It from bit. Otherwise put, every 'it'-every particle, every field of force, even the space-time continuum itself-derives its function, its meaning, its very existence entirely-even if in some contexts indirectly-from the apparatus-elicited answers to yes-or-no questions, binary choices, bits." [83].

E, the coherence remained within S is not complete, also the mixed state is not a complete state. Further, the E can again be divided into two parts: E_1 and E_2, and we view $S+E_1$ as the new system, then we can get another set of information. This division process can go further and further. This kind of structure of the world is coincident with the so-called "chinese pouring jacket", as shown in Figure 4.4 (up). We can still go further by another division. Every environment and also the system should have some structure, they could also be divided within themselves. Carry out this division until infinity. We finial get the net-like structure of the universe, which we can term as the "information-net", in Figure 4.4 (bottom) we show one 2-dimensional schematic map of this net. The universe is coherently connected by every part, and every part of the universe is connected with other parts. The universe is a coherent entity.

Till now, we should demonstrate that QM based on scope describes the universal correlations (or connections) among movements, it deals with information on a fundamental level.



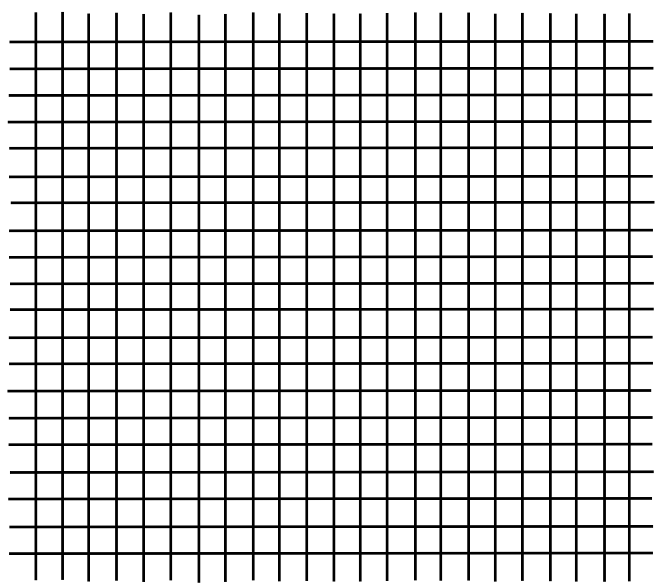


Figure 4.4: The Chinese pouring jacket (up); The information-net (infornet) of the universe (bottom).

4.3 Appendix

.

In this appendix, we re-interpret the classical EPR-paper [1]. The standpoint of EPR is often summed as "local realism". Below, we briefly recall the argument of EPR.

Firstly, there are two definitions, one is "reality", another is "completeness", as

Reality: "If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." And, "A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system."

Completeness: "Every element of the physical reality must have a counterpart in the physical theory." And, "In a complete theory there is an element corresponding to each element of reality."

Then after the study of the non-commutation relation, EPR gave two statements:

1. The quantum-mechanical description of reality given by the wave function is not complete.

2. When the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality.

One of them should be wrong. Then EPR studied the continuous variable entanglement example to prove that the statement 2 is wrong. There are two steps.

The first step: The systems I and II, after interacting within $(0,t)$, form the entangled state $\Psi(I,II)$. If the variables are x_1 and x_2, then

$$\Psi(I,II)=\sum_{n=1}^{\infty}\psi_n(x_2)u_n(x_1). \tag{4.22}$$

Let the observable A of I is $A(I)$, the measurement of A is $\mathcal{M}(A(I))$. After measurement, if we get u_k, then corresponding to $A(II)$, we get ψ_k. If we measure $B(I)$ by $\mathcal{M}(B(I))$ and get v_r, then corresponding to $B(II)$, we get ϕ_r. That is the entangled state

$$\Psi(I,II)=\sum_{n=1}^{\infty}\phi_n(x_2)v_n(x_1). \tag{4.23}$$

Then EPR argued that: "*Since at the time of measurement the two systems no longer interact, no real change can take place in the second system in consequence of anything that may be done to the first system.*" "*Thus, it is possible to assign two different wave functions (in our example ψ_k and ϕ_r) to the same reality (the second system after the interaction with the first.)*"

The second step: EPR gave an example to support the argument in the first step. Let A be the coordinate $\mathbf{p}$, B be the momentum $\mathbf{q}$. The entangled wave function is

$$\Psi(I, II) = \int e^{i(x_1 - x_2)\mathbf{p}/\hbar} d\mathbf{p}. \tag{4.24}$$

If we measure $\mathbf{p}(I)$ and get p, then for $\mathbf{p}(II)$ we get $-p$. If we measure $\mathbf{q}(I)$ and get x_1, then for $\mathbf{q}(II)$ we get x_2. So, system II have definite $-p$ and x_2 independent of the measurement of system I. That is, "*two physical quantities, with noncommuting operators, can have simultaneous reality.*"

At last, EPR stated that "*We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.*"

Next, we give a new interpretation of EPR argument, we state that the standpoint of EPR is not proper.

Firstly, for the single system, the non-commutation relation states that two non-commute quantities cannot have definite values at the same time, that is, they cannot have reality at the same time. EPR did not oppose this point.

Secondly, for the two-party system, the global state is entangled. The important thing is that how to construct this entangled state. If we want to know the state, measurement has to be carried out. Measurement is a kind of operator, when we measure, a special *representation* is selected out. If we can measure A, the measurement is $\mathcal{M}(A)$, the representation is one type, then the entangled state is Equation 4.22. If we can measure B, the measurement is $\mathcal{M}(B)$, the representation is another type, then the entangled state is Equation 4.23. The point is the two measurements are non-commute too, the same as the observable. That is, the non-commute measurements cannot be carried out at the same time. For example, for the free particle $\psi = e^{ipx/\hbar}$. If we measure $\mathbf{p}$, then the representation is of coordinate, $\mathbf{p} = -i\hbar\frac{\partial}{\partial x}$, $\mathbf{p}\psi = p\psi$. The momentum has definite value, and the coordinate does not. If we measure $\mathbf{q}$, then the representation is of momentum, $\mathbf{q} = i\hbar\frac{\partial}{\partial p}$, $\mathbf{q}\psi = -x\psi$. The coordinate has definite value, and the momentum does not.

Thirdly, the definition of reality is not proper. It does not distinct between "reality" and "the outcomes we measure of the reality". Before measurement, there *is* reality of the system. However, every measurement is not "complete", it can only select out a particular kind of outcomes. With each measurement, we can predict with certainty the value we can get. With all the measurements, the whole reality of the system can be well measured. According to our interpretation of quantum mechanics based on *scope*, the wave function is indeed the scope, describing the structure of motion systematically, it have two properties, the "reality" and "propensity" (see Chapter 2: Property 4). The state of the system can change from propensity to reality when measurement is performed. The description based on scope demonstrates the "process", "interaction", or "connection" between the system and our measurement. The definition of "reality" by EPR only cares about the "system" aspect, thus, it is not proper. The definition of "completeness" relies on that of reality, thus, it is not proper, either.

In all, as we have pointed out, the "local realism" originates from the casual dynamics description of classical mechanics (Chapter 1), which is different from the description of quantum mechanics. Then we have to conclude that the argument of EPR is not proper.

Bibliography

[1] A. Einstein, B. Podolsky, N. Rosen, *Can quantum-mechanical description of physical reality be considered complete?*, Phys. Rev. **47**, 777-780 (1935).

[2] D. Bohm, *A suggested interpretation of the quantum theory in terms of "hidden variables"*, I and II, Phys. Rev. **85**, 166-193 (1952).

[3] J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics* (Cambridge University Press, Cambridge, England, 1987).

[4] A. Aspect *et al.*, *Experimetal Tests of Bell' s Inequalities Using Time-Varying Analysers*, Phys. Rev. Lett. **49**, 1804-1807 (1982).

[5] R. J. Glauber, *Coherent and Incoherent States of the Radiation Field*, Phys. Rev. **131**, 2766-2788 (1963).

[6] A. Miranowicz *et al.*, *Testing nonclassicality in multimode fields: A unified derivation of classical inequalities*, Phys. Rev. A **82**, 013824 (2010), and references therein.

[7] R. Horodecki, P. Horodecki, M. Horodecki, and K. Horodecki, *Quantum entanglement*, Rev. Mod. Phys. **81**, 865-942 (2009).

[8] L. de Broglie, *An Introduction to the Study of Wave Mechanics*, (E. P. Dutton and Co., New York, 1930).

[9] L. de Broglie, *The Reinterpretation of Wave Mechanics*, Found. Phys, **1**, 5-15 (1970).

[10] D. J. Bohm and B. J. Hiley, *The de Broglie Pilot Wave Theory and the Further Development of New Insights Arising Out of It*, Found. Phys, **12**, 1001-1016 (1982).

[11] J. S. Bell, *On the Impossible Pilot Wave*, Found. Phys, **12**, 989-999 (1982).

[12] C. Dewdney, G. Horton, M. M. Lain, Z. Malik, and M. Schraidt, *Wave-Particle Dualism and the Interpretation of Quantum Mechanics*, Found. Phys, **22**, 1217-1265 (1992).

[13] A. J. Leggett, *Nonlocal Hidden-Variable Theories and Quantum Mechanics: An Incompatibility Theorem*, Found. Phys, **33**, 1469-1493 (2003).

[14] J. F. Clauser, M. A. Horne, A. Shimony, and R. A. Holt, *Proposed experiment to test hidden variable theories*, Phys. Rev. Lett. **23**, 880-883 (1969).

[15] B. S. Tsirelson, *Quantum Generalizations of Bell's Inequality*, Lett. Math. Phys. **4**, 93 (1980).

[16] N. Gisin, *Bell inequalities: many questions, a few answers*, arXiv:quant-ph/0702021 (2007).

[17] S. Popescu and D. Rohrlich, *Quantum nonlocality as an axiom*, Found. Phys. **24**, 379 (1994).

[18] D. Gross, M. Mueller, R. Colbeck, and O. C. O. Dahlsten, *All reversible dynamics in maximally non-local theories are trivial*, (2009) (arXiv.org/quant-ph/0910.1840).

[19] M. D. Reid, *Demonstration of the Einstein-Podolsky-Rosen paradox using non-degenerate parametric amplification*, Phys. Rev. A **40**, 913-923 (1989).

[20] H. M. Wiseman, S. J. Jones, and A. C. Doherty, *Steering, Entanglement, Nonlocality, and the Einstein-Podolsky-Rosen Paradox*, Phys. Rev. Lett. **98**, 140402 (2007).

[21] E. G. Cavalcanti, S. J. Jones, H. M. Wiseman, and M. D. Reid, *Experimental criteria for steering and the Einstein-Podolsky-Rosen paradox*, Phys. Rev. A **80**, 032112 (2009).

[22] M. D. Reid *et al.*, *The Einstein-Podolsky-Rosen paradox: From concepts to applications*, Rev. Mod. Phys. **81**, 1727-1751 (2009).

[23] R.F. Werner, *Quantum States with Einstein-Podolsky-Rosen correlations admitting a hidden-variable model*, Phys. Rev. A **40**, 4277 (1989).

[24] S. Popescu, *Bell inequalities and Density Matrices: Revealing "Hidden" Nonlocality*, Phys. Rev. Lett. **74**, 2619 (1995).

[25] R.F. Werner and M.M. Wolf, *Bell inequalities and entanglement*, http://arxiv.org/abs/quant-ph/0107093v2.

[26] D. Collins, N. Gisin, N. Linden, S. Massar, and S. Popescu, *Bell Inequalities for Arbitrarily High-Dimensional Systems*, Phys. Rev. Lett. **88**, 040404 (2002).

[27] N. D. Mermin, *Extreme Quantum Entanglement in a Superposition of Macroscopically Distinct States*, Phys. Rev. Lett. **65**, 1838 (1990).

[28] M. Ardehali, *Bell inequalities with a magnitude of violation that grows exponentially with the number of particles*, Phys. Rev. A **46**, 5375 (1992).

[29] A. V. Belinski and D. N. Klyshko, *Interference of light and Bell's theorem*, Phys. Usp. **163**, 1 (1993).

[30] E. G. Cavalcanti, C. J. Foster, M.D. Reid, and P. D. Drummond, *Bell Inequalities for Continuous-Variable Correlations*, Phys. Rev. Lett. **99**, 210405 (2007).

[31] D. M. Greenberger, M. A. Horne, and A. Zeilinger, *Going Beyond Bell's Theorem in Bell's Theorem, and Conceptions of the Universe* (Kluwer Academic, Dordrecht, 1989).

[32] D. M. Greenberger, M. A. Horne, A. Shimony, and A. Zeilinger, *A Bell's theorem without inequalities*. Am. J. Phys. **58**, 1131 (1990).

[33] D. M. Greenberger, M. A. Horne, and A. Zeilinger, *Multiparticle interferometry and the superposition principle*. Phys. Today **8**, 22-29 (1993).

[34] A. Peres, *Separability Criterion for Density Matrices*, Phys. Rev. Lett. **77**, 1413 (1996).

[35] G. Vidal and R. F. Werner, *Computable measure of entanglement*, Phys. Rev. A **65**, 032314 (2002).

[36] C. H. Bennett, H. J. Bernstein, S. Popescu, B. Schumacher, *Concentrating partial entanglement by local operations*, Phys. Rev. A **53**, 2046 (1996).

[37] S. Hill and W. K. Wootters, *Entanglement of a Pair of Quantum Bits*, Phys. Rev. Lett. **78**, 5022 (1997).

[38] W. K. Wootters, *Entanglement of Formation of an Arbitrary State of Two Qubits*, Phys. Rev. Lett. **80**, 2245 (1998).

[39] C. H. Bennett, D. P. DiVincenzo, J. A. Smolin, and W. K. Wootters, *Mixed-state entanglement and quantum error correction*, Phys. Rev. A **54**, 3824 (1996).

[40] P. M. Hayden, M. Horodecki, B. M. Terhal, *The asymptotic entanglement cost of preparing a quantum state*, J. Phys. A: Math. Gen. **34**, 6891-6898, (2001).

[41] M. Horodecki, P. Horodecki, R. Horodecki, *Mixed-State Entanglement and Distillation: Is there a "Bound" Entanglement in Nature?*, Phys. Rev. Lett. **80**, 5239 (1998).

[42] R. Simon, *NPPT Bound Entanglement Exists*, e-print arXiv:quant-ph/0608250.

[43] L. Pankowski, M. Piani, M. Horodecki, and P. Horodecki,, *A Few step towards NPT bound entanglement*, e-print arXiv:quant-ph/0711.2613.

[44] B. M. Terhal, *Bell inequalities and the separability criterion*, Phys. Lett. A **271**, 319 (2000).

[45] O. Gühne and N. Lütkenhaus, *Nonlinear Entanglement Witnesses*, Phys. Lett. Lett. **96**, 170502 (2006).

[46] M. Kotowski, M. Kotowski, and M. Kuś, *Universal nonlinear entanglement witnesses*, Phys. Lett. A **81**, 062318 (2010).

[47] F. G. S. L. Brandão, *Quantifying entanglement with witness operators*, Phys. Rev. A **72**, 022310 (2005).

[48] V. Vedral and M. B. Plenio, *Entanglement measures and purification procedures*, Phys. Rev. A **57**, 1619-1633 (1998)

[49] D. Deutsch, *Uncertainty in Quantum Measurements*, Phys. Rev. Lett. **50**, 631 (1983).

[50] K. Kraus, *Generalized Entropic Uncertainty Relations*, Phys. Rev. D **35**, 1103 (1987).

[51] H. Maassen and J. B. M. Uffink, *Generalized Entropic Uncertainty Relations*, Phys. Rev. Lett. **60**, 1103 (1988).

[52] O. Gühne and M. Lewenstein, *Entropic Uncertainty Relations and entanglement*, Phys. Rev. A **70**, 022316 (2004).

[53] J. I. de Vicente and J. Sánchez-Ruiz, *Improved bounds on entropic Uncertainty Relations*, Phys. Rev. A **77**, 042110 (2008).

[54] H. F. Hofmann and S. Takeuchi, *Violation of local uncertainty relations as a signature of entanglement*, Phys. Rev. A **68**, 032103 (2003).

[55] H. F. Hofmann, *Bound entangled states violate a nonsymmetric local uncertainty relation*, Phys. Rev. A **68**, 034307 (2003).

[56] O. Gühne, *Characterizing Entanglement via Uncertainty Relations*, Phys. Rev. Lett. **92**, 117903 (2004).

[57] A. Serafini, *Multimode Uncertainty Relations and Separability of Continuous Variable States*, Phys. Rev. Lett. **96**, 110402 (2006).

[58] H. Nha and M. S. Zubairy, *Uncertainty Inequalities as Entanglement Criteria for Negative Partial-Transpose States*, Phys. Rev. Lett. **101**, 130402 (2008).

[59] T.-C. Wei and P. M. Goldbart, *Geometric measure of entanglement and applications to bipartite and multipartite quantum states*, Phys. Rev. A **68**, 042307 (2003).

[60] G. Vidal and R. Tarrach, *Robustness of entanglement*, Phys. Rev. A **59**, 141 (1999).

[61] M. Steiner, *Generalized robustness of entanglement*, Phys. Rev. A **67**, 054305 (2003).

[62] O. Rudolph, *Further results on the cross norm criterion for separability*, e-print arXiv:quant-ph/0202121.

[63] C. J. Zhang, Y. S. Zhang, S. Zhang, and G. C. Guo, *Entanglement detection beyond the computable cross-norm or realignment criterion*, Phys. Rev. A **77**, 060301(R) (2008).

[64] O. Gühne, P. Hyllus, O. Gittsovich, and J. Eisert, *Covariance Matrices and the Separability Problem*, Phys. Rev. Lett. **99**, 103504 (2007).

[65] O. Gittsovich, O. Gühne, P. Hyllus, and J. Eisert, *Unifying several separability conditions using the covariance matrix criterion*, Phys. Rev. A **78**, 052319 (2008).

[66] I. I. Rabi, *Space Quantization in a Gyrating Magnetic Field*, Phys. Rev. **51**, 652 (1937).

[67] P. G. Kwiat, K. Mattle, H. Weinfurter, and A. Zeilinger, *New High-Intensity Source of Polarization-Entangled Photon Pairs*, Phys. Rev. Lett. **51**, 4337 (1995).

[68] H. Ollivier and W. H. Zurek, *Quantum Discord: A Measure of the Quantumness of Correlations*, Phys. Rev. Lett. **88**, 017901 (2002).

[69] W. H. Zurek, *Quantum discord and Maxwell's demons*, Phys. Rev. A **67**, 012320 (2003).

[70] K. Modi, T. Paterek, W. Son, V. Vedral, and M. Williamson, *Unified View of Quantum and Classical Correlations*, Phys. Rev. Lett. **104**, 080501 (2010).

[71] M. Kuś and K. Zyczkowski, *Geometry of entangled states*, Phys. Rev. A **63**, 032307 (2001).

[72] J. M. Leinaas, J. Myrheim, and E. Ovrum, *Geometrical aspects of entanglement*, Phys. Rev. A **74**, 012313 (2006).

[73] M. Lewenstein and A. Sanpera, *Separability and Entanglement of Composite Quantum Systems*, Phys. Rev. Lett. **80**, 2261 (1998).

[74] H. D. Zeh, *On the interpretation of measurement in quantum theory*, Found. Phys. **1**, 69-76 (1970); *Toward a quantum theory of observation*, Found. Phys. **3**, 109-116 (1973).

[75] W. H. Zurek, *Pointer basis of quantum apparatus: Into what mixture does the wave packet collapse?*, Phys. Rev. D **24**, 1516-1525 (1981); *Environment-induced superselection rules*, Phys. Rev. D **26**, 1862-1880 (1982).

[76] W. H. Zurek, *Decoherence, einselection, and the quantum origins of the classical*, Rev. Mod. Phys. **75**, 715-775 (2003).

[77] W. H. Zurek, *Relative states and the environment: Einselection, envariance, quantum Darwinism, and the existential interpretation*, eprint arXiv:quant-ph0707.2832.

[78] M. Schlosshauer, *Decoherence, the measurement problem, and interpretations of quantum mechanics*, Rev. Mod. Phys. **76**, 1267-1305 (2004).

[79] V. B. Braginsky and F. Ya. Khalili, *Quantum nondemolition measurements: the route from toys to tools*, Rev. Mod. Phys. **68**, 1-11 (1996).

[80] M. Schlosshauer, and A. Fine, *On Zurek's Derivation of the Born Rule*, Found. Phys. **35**, 197-213 (2005).

[81] M. Zukowski, A. Zeilinger, M.A. Horne, and A. Ekert, *"Event-ready-detectors" Bell experiment via entanglement swapping*, Phys. Rev. Lett. **71**, 4287 (1993).

[82] J. W. Pan, D. Bouwmeester, H. Weinfurter, and A. Zeilinger, *Experimental Entanglement Swapping: Entangling Photons That Never Interacted*, Phys. Rev. Lett. **80**, 3891 (1998).

[83] From wikipedia, http://en.wikipedia.org/wiki/John Archibald Wheeler.

Chapter 5

Entanglement: Application

5.1 Photocule Physics and Engineering

.

5.1.1 Motivation

.

The theory of field has existed from the time of Faraday. However, he did not know what field exactly is, neither Maxwell who formed the equations of field later. It was Einstein who termed "photon" to stand for the element of field, and viewed field as a special kind of matter, whose propagation does not need any medium. Before Einstein, Planck introduced the quanta of the energy of light as $E = h\nu$, which is one of the most important equations in physics. And, according to Special Relativity (SR), the energy of light can be $E = mc^2$. Thus, naturally, if we view field can have mass and momentum, then

$$mc^2 = h\nu. \tag{5.1}$$

In quantum theory, the movement of particles, such as "jump", has neatly connection with photon. Thus, de Broglie thought that the relation can not only be used for light, it should be universal, including massive particles, such as electron. He introduced the corresponding wave to the particle with mass m as real "matter wave" [1]. As we know, this method helped Schrödinger to form the wave mechanics [2]. In the standard interpretation of QM, the micro-element (particle) is not particle or wave, it is "particle and wave", which means that the particle can perform both classical particle property and wave property, but not both of them at the same time. This "wave-particle duality" is viewed as that there is no classical correspondence [3]. And the wave function is interpreted as "the probability amplitude". In contrast, this is not what de Broglie thought. Around 1927, he developed the "pilot wave" approach, in which the particle with definite local form sits at a certain place in the real pilot wave, and the particle can be viewed as the high-energy concentrate singularity of the wave [4]. The difference between de Broglie's and the orthodox interpretation was ignored until in 1952 Bohm formed a kind of hidden variable theory (HVT), the Bohm mechanics (BM).[1] According to this casual interpretation, the reason of probability is that there is the un-described hidden variable λ, which determines the dynamics. The wave function is a kind of "guide wave", which forms the "quantum potential", and decides the trajectories of particles with different initial condition. As a result, the orthodox probabilistic interpretation of wave function, the wave-particle duality are not proper in the Bohm mechanics.

5.1.2 Potocule

.

Above we briefly recall the historical material useful for this section. In this section, we present our interpretation of field and light (without related to ether, as discussed in Chapter 7), and discuss the applications of light: the *photocule physics*. According to our interpretation based on *scope*, the probabilistic interpretation of wave function should remain, although modified a little. For the wave-particle duality, as we discussed in chapter 3, the relation $mc = h/\lambda$ stands for the individuality (particle) and collectivity (wave) properties of the motion of micro-element particle. There is no "matter wave", wave is not a kind of matter, instead it is a kind of movement of matter. We do not know "what the particle, such as electron, looks like", so we could not say the electron is "wave and particle", what we only should say is the motion of electron has the property of "wave and particle", exactly, the "systematics" which is the unification of individuality and collectivity (as we termed in Chapter 3). Then, from our interpretation, photon is not some matter, it is a "packet of energy", it is the basic element of motion (we may ask "whose motion?", this question is answered in Chapter 7). For BM, it inherits the casual dynamical description from classical mechanics, thus, it is different from the standard QM. By viewing *scope* as physical quantity, and giving the particle a hidden variable, it can describe the physical process more precisely. So, the standard QM (wave, matrix mechanical forms) can not give the detailed dynamical process. The BM can be viewed as a combination of the casual description and the QM method.

However, when we do not care about the dynamics, instead energy is mainly cared, under this condition, a wave can properly be viewed as the motion of particle, and the wave itself can also properly be viewed as a kind of matter. This wave-particle equivalence can be expressed as

$$mc^2 \equiv h\nu.^{2} \tag{5.2}$$

[1]There is a little difference between de Broglie and Bohm, please see Ref. [5].

[2]We should demonstrate again that the left and right hand sides of the equation are different,

After these classification of the basic concept, what we meant to do is to study to what extent the properties of particle (matter) and wave (field) are similar with each other.

The comparison is summed in the table below.

Table 5.1: The comparison of the properties of matter and field.

	matter	field
character	m (quantized)	λ (continuous)
element	particle	photon
spin	magnetism	polarization
charge	positive, negative	no charge ???
interaction	BEC, plasma,...	natural, laser, squeezed,...
transform	nuclear reaction	non-linear optics
structure element	atom, molecule	???
density	solid, liquid, gas,...	???
purity	simple substance, mixture, compound	natural light, single/multi-mode laser
distribution	limited volume	infinite boundary

However, this comparison is far-more complete. For example, can the concept "density" be applied to field? If we accept the "energy density", so, are there some special energy densities for field? Also, what is the element of field? Anything beyond photon? In our standard theory (the quantum field theory [6]), the field (photon) is viewed to provide the interactions between particles, and particles are thought coming from field during the early age of the universe. However, we still do not know the "origin of mass". And, although chemists can synthesize compound nowadays, we still do not able to create one atom. Our quantum field theory (QFT), though considered complete, is far more enough to explain the exact characters of field, at least the unified theory of field is not achieved.

For another thing, as we know, there are interactions between light and matter (atom, molecule, etc.). For instance, the state of atom can change by absorption or emission of photons. One beam of light with a certain frequency can be transformed to another two beams with frequencies by nonlinear process with the help of atom, which is the standard second-harmonic generation process [7]. Also, photons can be generated through the nuclear reaction. However, can particles be generated through some purely photon process? This question can not be answered as long as we do not know the origin of mass.

physically.

So, from our standard theory, it seems that matter is more advanced or evolved than field in our universe, then matter is more familiar to us in many ways. But, if we take it from another point, there should be some symmetry or equivalence between them, as the wave-particle duality suggests. So we make the following hypothesis:[3]

Hypothesis: There is a certain one-to-one correspondence between the characters of field and matter.

From this hypothesis, a direct result is the existence of the "photocule", termed as the combination of "photon" and "molecule", to stand for the compound of field, the correspondence of the molecule of matter. In fact, there exist some promising hints for the existence of photocule.

One example comes from molecule obviously. Molecule is made of atoms, and the chemical bond relies on the entanglement of the states of the electron [8]. This entanglement is Tq, ensemble of electrons are not needed. Without the entanglement, the molecules and even atoms could not be formed.

Another example is the teleportation in quantum information processing [9]. This process uses the light sources from the type-II SPDC by interacting with the nonlinear crystal, one photon from the pump beam can be transformed to a pair of photons: the ideal and signal photons, the global state, as a whole, is the entangled state of polarization:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|H_i V_s\rangle - |V_i H_s\rangle). \tag{5.3}$$

If we can know the ideal photon ω_i is horizontal, then we know the corresponding signal photon ω_s is vertical, and vice versa. If we make Bell measurement of one of the photon (such as the ideal photon) and another initial photon, then the state of this photon can be realized by the signal photon. In this entangled state, the photon in the ideal channel can be horizontal or vertical, also the photon in the signal channel. Indeed, this state is the entanglement of the two modes (channel) of photon, not exact two photon. From our classification of state, this state is a multifold Ei entangled state. This state has some molecular properties: it has two components, and these two parts entangle together. This state can be viewed as a kind of "pseudo-photocule". Since this state should involve many photons, it is not a real photocule.

So, is it possible to form some photocule based on the entanglement between photons? In my view, it is possible, but with great difficulty. Firstly, we need to separate a single photon out from the field, like the same situation that we now can separate a single atom using the laser cooling technique. Secondly, we need to localize the photon, and generate some nonlinear interactions between photons,

[3] This hypothesis does not conflict with any principles in physics at present.

these technique are not achievable at present. Thirdly, we need to make sure that the photocule has a steady structure. And there should be other things to make sure. However, if one day we can realize or find the photocule, our physics, technique, and engineering will be greatly changed, and we will find the exquisite structure and properties of light and field.

From historical view, it is quite possible to welcome the photocule physics and engineering. The 20th century is mainly the era of electron. Our theory, from the theory of ether and micro-particle to Lorenze's theory of electron, from wave mechanics to the elementary particle physics, also the application, from semiconductor to mobile, from chip to internet, etc. have greatly enlarged our knowledge. At the same time, the theory and application of light (photon) also achieved a lot in the 20th century, however, it turns out that there should be a long way ahead. Anyway, the essence of field is not yet clear.

5.2 Quantum Communication, Computation, and Control (QC^3)

.

Quantum communication and Quantum computing, also termed as Quantum information processing and Quantum computing (QIQC), are now one of the most promising field in physics, also, Quantum control and the related Atom, Molecule, and Optics (AMO) are flourishing. These great advance in physics, technology, and engineering are all based on the principle of QM. There is no need to recall the development of QC^3, here, we may discuss something about the fundamental propulsion of these research.

Historically, the origin of quantum information is thermodynamics (TD). TD completes the principles of energy and entropy. Initially, information is defined by Shannon as the negentropy. The classical information physics and engineering should be viewed as the first application of TD. Classical information theory (CIT) is one of the "new science" emerged in the late 20th century, together with "system theory", "synergetics", "mutationism", "dissipative structure theory", etc.. The quantum information is indeed a combination of CIT and QM, which should be viewed as the second application of TD. Also, QM shows some more fundamental features than TD. Thus, it is possible to build TD on QM. If this kind of unification is reached, it is a real further big step for TD. After that, we can see that the information theory is finally based on QM. QM itself ensures the power of the development of QC^3.

However, at present, there exist many bottlenecks for QC^3, which need lots of efforts and also the examination on QM. One is the technical bottleneck. The elementary problem of application of a theory is always technical. At present, there is no well-established quantum frame, channels, chips, sources to accomplish the communication and computation, also the modern control technic of single photon, ion, atom, quantum dot, etc. is not well-skilled. Most of the experiments are primary and cost a lot. There still is a long way for the quantum channel and computer to work in a real circumstance.

Another aspect is theoretical. There really exist a mount of problems ahead of QC^3. Firstly, the relation between TD and QM. Although this issue has been studied for a long time, the relation has not yet been set up. Is QM really the foundation of TD? Secondly, the foundation of information theory. Often we view there exist two kinds of information theory, classical and quantum. However, the classical physics should be an approximation or limit of quantum physics, so the information theory should be based on QM, which has not been done yet. Thirdly, the problems of QM itself. QM as a theory is not well interpreted, thus there must be confusion to use its principle for application. Forth, the theory of quantum entanglement. Entanglement plays the central role in QM and QC^3, however, people do not really know what it is, such as, is entanglement the same or similar with entropy? is there a unique detector for a certain entangled state? is entanglement in conflict with the principle of Relativity? And, another one, are the quantum effects only available on microscopic scale?

Besides the bottlenecks both technical and theoretical, in practice, it needs the well collaboration of various researchers and students from different subjects, such as computing, engineering, chemistry, biology, etc.. Nowadays, internationalization is the basic character of science and scientific research. The benefit of international collaboration has been proven by the achievement of Niels Bohr Institute. A well organized international research community of QC^3 is necessary for the development of QC^3.

In addition, QC^3 can further shed light on the physics of photocule. If we can manipulate photon, atom, etc. freely, then to manipulate the elementary particle, the field, and the photocule is not far away.

Bibliography

[1] L. de Broglie, *An Introduction to the Study of Wave Mechanics* (E. P. Dutton and Co., New York, 1930).

[2] E. Schrödinger, *An Undulatory Theory of the Mechanics of Atoms and Molecules*, Phys. Rev. **28**, 1049-1070 (1926).

[3] N. Bohr, *Atomic Theory and the Description of Nature* (Cambridge Univ. Press, New York, 1934), p. 10.

[4] L. de Broglie, J. Physique (serie 6) VIII (5), 225 (1927).

[5] C. Dewdney, G. Horton, M. M. Lain, Z. Malik, and M. Schraidt, *Wave-Particle Dualism and the Interpretation of Quantum Mechanics*, Found. Phys **22**, 1217-1265 (1992).

[6] S. Weinberg, *The Quantum Theory of Fields* (three volumes: 1995, 1996, 2003).

[7] R. W. Boyd, *Nonlinear Optics* (second edition, Academic Press, an imprint of Elsevier Science, 2003).

[8] K. Ryedenberg, *The Physical Nature of the Chemical Bond*, Rev. Mod. Phys. **34**, 326-376 (1962); J. E. House, *Fundamentals of Quantum Chemistry* (second edition, Academic Press, an imprint of Elsevier Science, 2004).

[9] D. Bouwmeester, J. Pan, K. Mattle, M. Eibl, H. Weinfurter, and A. Zeilinger, *Experimental quantum teleportation*, Nature **390**, 575-579 (1997).

Chapter 6

Relativity and Quantum Mechanics

In this chapter, we turn to a more fantastic problem: the relation between quantum mechanics (QM) and Relativity. We should state that for QM, we seldom mean quantum field theory (QFT), since we view field description not the same as the systematical description of QM. Nowadays, in QFT one of the main problem is the superluminal of light, for example, there exist many proposals allowing tachyon. However, this problem lies in the field theory, thus for QM, we should always maintain the consistency of the speed of light. Also, we mainly study the Special Relativity (SR), we may study the problems of General Relativity (GR) elsewhere. Below, we try to clarify the essence of SR, and combine the foundations of SR and QM together, also we make a further step to explore the methods to unify them.

6.1 Re-interpretation of Relativity

.

6.1.1 Introduction

.

The attempt from principle to unify QM and Relativity never stops, such as Ref. [1, 2, 3]. Also, for Relativity, there exist many different interpretations not the same with the standard one, see Ref. [4, 5, 6, 7, 8, 9] for example. Before our study, we should be sure what Relativity exactly is. One of the effective ways to grasp the essence of one theory is to look at its origin. In history, SR is mainly dedicated to Einstein, while its origin may lie earlier at Mach's work [10]. Mach's criticism of Newton mechanics shed new light on the future physics at that time. He criticized the absolute view of space and time, which has a significant influence on Einstein. Also Mach studied the relativity of motion, and raised the famous principle, Mach's principle as we know. This principle has lots of different formulation, the common one is expressed as: local inertial frames are affected by the cosmic motion and distribution of matter.[1] The other two mainly pioneers of SR are Poincaré and Lorenze. Generally, Poincaré is not only a mathematician, but also a physicist, and a philosopher as "conventionalist". In his later years, he was immersed in the study of absolute motion, which later directed him to the construction of the *Postulate of Relativity* [11, 12, 13, 14]. Though widely studied, it is not easy to clarify the essence of Poincaré's theory, there still exist disagreement.[2] In my view, at least in 1895, Poincaré reached the principle of the non-measurability of the absolute motion. He said that: "it is impossible to detect the absolute movement of matter, or better, the relative movement of ponderable matter in relation to the ether; all that one can find evidence of is the movement of ponderable matter in relation to ponderable matter. [9]" In 1904, he found the Postulate of Relativity. Below, we give our understanding of his theory, we try our best to make sure not to miss any important idea.

1. Local time is physical, also the contraction, related to the "Poincaré stress".

2. He did not deny the existence of ether, he only denied the possibility to detect it [17]. That is, at least, he did not abandon the possibility of a dynamics.

3. Lorenze transformation is linked to the methods of measurement. Space and time are the concepts used to measure the movement.[3] And, there is a tension between the metrical method and dynamical method in his theory, as he said we "have no way of knowing whether it is the magnitude [of length] or the instrument which has changed. [16]"

4. Gravitational force should transfer with the speed of light, like the electromagnetic force. That is to say, the Postulate of Relativity is not limited in the inertial system as the SR did in 1905. Poincaré's relativity could be applied to all the forces.

5. He did not agree with the world-view of electromagnetism [15], since not everything in the world is of electromagnetic origin. This standpoint is important to criticize the ambition of electromagnetism, which is requested to construct the relativity of gravity.

6.1.2 Principle of Relativity

.

[1] This principle is consistent with the principle of the coherence of the universe (PCU), as we studied in Chapter 4. Both of them demonstrate the connection among the parts of the universe, and the wholeness of the universe as an inseparable entity. The difference is that Mach's principle relies on the method of interaction, while PCU relies on the methods of entanglement and information.

[2] For example, see the notable book written by Whittaker [15].

[3] For the view of measurement, we have construct a model in Chapter 1.

From the brief study above, at least we can see the essence of Poincaré's theory. In contrast to the SR, Poincaré's relativity is more general and complete in about two aspects. One is that it maintains the existence of ether, another is that it actually include the special and general relativity of Einstein. We may say that Einstein's work, including the GR in 1915, and the work on unified field theory hereafter are all within the range of Poincaré's relativity.

Next, we compare the relativity of Poincaré (from 1895) and the SR of Einstein (1905) in detail. Although the two theories both aimed to solve the same thing, the relativity of motion, their approaches are different. Here there is no need to restate the SR. We can see the difference between them from the following table.

Table 6.1: The comparison of the Relativity of Poincaré and Einstein.

	Poincaré	Einstein
ether	exist	not exist
absolute motion	not measurable	not exist
relative motion	all kinds	inertial
force	all kinds	electromagnetic
speed of light	constant, largest	constant, not largest
space and time	as measurable property	as entity
mass-energy relation	no	yes
photon	no	yes
Poincaré group	yes	no
philosophy	relativity of motion, conventionalism	relativity of space-time

Here we should pointed out that in their theories, mainly another two people, Lorenze and Minkowski also contributed a lot [18, 19, 20]. From the table, we can draw that the SR has several characters. Firstly, it is kinematical, there is no dynamical approach to the Lorenze transformation. The reason may be that Einstein took space and time as the external measurement, the ruler and the clock, and he abandoned ether and constructed the new concept of photon, which is "a packet of energy".[4] Secondly, the two standpoints, relativity of space-time and space-time as entity, conflict with each other in SR. Actually, it is not very clear in Einstein's theory that whether space-time is a description of motion or entity different from common matter. On the contrary, there is no this conflict

[4]Indeed, we can view this change as from the force description to the energy description, as discussed in Chapter 1. For the relation between ether and SR, please see Chapter 7.

in Poincaré's theory, since the entity light propagates in is ether underlying, also space and time are the properties of motion when we carry out measurement.

Before we end the discussion of SR, we should mention the work of Lorenze. Though it take quite a long time to accept the physical essence of local time, the introduction of the concept of "corresponding state" between a moving frame and the "true" frame of a stationary ether, is really genius [18, 19]. The corresponding states connect with each other by the Lorenze transformation. Particularly, the view of "state" is in consistent with the method of QM. Below we will show that the SR, and the corresponding state principle of Lorenze transformation (we may name it as a principle) are all connected with the superposition principle of scope in QM.

In all, we spend so much time above to study the history of relativity, as a result, we have to state that a complete theory of SR should at least have two aspects: the dynamical approach and the kinematic approach. This division is due to historical reason as studied above. Unfortunately, there is no definite dynamical approach even nowadays. One of the main reasons should be that there is no ether theory in SR, as we will point out in Chapter 7. Physically, the fundamental principle of Relativity is the non-measurability of absolute motion, every other results of Relativity are the consequence of this principle.

The logic of relativity should be
the non-measurability of absolute motion
→ *the measurability of relative motion*
→*the equivalence of relative motion*
→*the consistency of the speed of light*
→*the equivalence of space and time, the equivalence of mass and energy, the length contraction, the time dilation, the Lorenze transformation.*

In addition, for GR, the third step has to be modified, that the consistency of speed of light is not realized in the Euclidian geometry; then in the forth step, the Lorenze transformation is modified, and new things like curved space-time emerge.

From this point, we have clarified the essence of SR. The foundation lies on the principle of the non-measurability of absolute motion, which seems right and reasonable. At least there is no way for us to know the universe as a whole is moving or not. This principle is related to the following two problems: the existence of ether, and the foundation of QM. We will talk about ether in the next chapter. Below, let us turn to the relation between QM and SR.

6.2 Unification of QM and Relativity

.

In this part, we prove that the principle of relativity is consistent with the principle of superposition and entanglement. This is a widely discussed, argued, and not yet solved problem. From our interpretation, this problem is indeed that to find the relationship between the two distinct descriptions of motion, that is, the QM and CM.

First, we need to re-consider the mathematical form of SR, mainly, the Lorenze transformation and the velocity-adding law. To deduce the Lorenze transformation, there exist two kinds of models. In the first one ($1M2S$-type), one object M is measured in two frames $S(x,t)$ and $S'(x',t')$, and S' has the velocity v relative to S. The observer in S and S' get different results of time, distance, and velocity. In the second one ($2M1S$-type), two objects M_A and M_B move in the same frame $S(X,T)$.[5] There is one inherent frame each on the object, and there exists the relative velocity between them. Here, we employ the second model, since we think it is more natural. In the second model, the relative motion is directly the relative motion between the two motions of M_A and M_B, instead of from the two measurements in the two frames S and S'. Since relative motion is represented as velocity, the second model is more direct to show the physical meaning of the velocity-adding law.

Here we construct one simple model. Suppose the motions of M_A and M_B are 1-D along the X-axe, and it is easy to generalize to the 3-D condition, and the physical essence is the same. The model is shown in Figure 6.1. Let the velocity of M_A is $\mathcal{V}_A = x/t$, and the velocity of M_B is $\mathcal{V}_B = x'/t'$, the relative velocity from M_A to M_B is $\mathcal{V}_0$. Then from SR, we can get

$$\mathcal{V}_A = \frac{\mathcal{V}_B - \mathcal{V}_0}{1 - \mathcal{V}_B\mathcal{V}_0/c^2}, \tag{6.1}$$

this form can be changed to a more symmetrical one:

$$\mathcal{V}_0 = \frac{\mathcal{V}_B - \mathcal{V}_A}{1 - \mathcal{V}_B\mathcal{V}_A/c^2}. \tag{6.2}$$

This equation is the essence of SR. In the Galileo relativity, $\mathcal{V}_0 = \mathcal{V}_B - \mathcal{V}_A$.

Now, based on SR, we know the maximal speed of one object is the speed of light c,[6] and of course the minimal speed is *zero*. The speed space forms one *sample probability space*. Define $\mathcal{P} = v/c$ as the *speed weight* of one motion. When $v = 0$, it means the weight of the motion in the probability space is zero. When $v = c$, it means the weight of the motion in the probability space is maximal, and the motion is certain. From the probability view, Equation 6.2 can be written as

$$\mathcal{P}_0 = \frac{\mathcal{P}_B - \mathcal{P}_A}{1 - \mathcal{P}_B\mathcal{P}_A}, \tag{6.3}$$

[5]Here, we'd better not view $S(X,T)$ as the absolute frame, instead, the existence of this frame only means that there exist space and time.

[6]The speed of light can be explained as the speed of energy transfer in "ether". Since every object is a special state of ether, the interaction between objects rely on ether, then the speed of ponderable object can not add into the speed of light.

where $\mathcal{P}_0 = \mathcal{V}_0/c$, $\mathcal{P}_A = \mathcal{V}_A/c$, $\mathcal{P}_B = \mathcal{V}_B/c$.

Further, we introduce the following quantities

$$\begin{aligned} \alpha &= 1 - \mathcal{P}_A, \alpha' = 1 + \mathcal{P}_A, \\ \beta &= 1 - \mathcal{P}_B, \beta' = 1 + \mathcal{P}_B, \\ \gamma &= 1 - \mathcal{P}_C, \gamma' = 1 + \mathcal{P}_C. \end{aligned} \tag{6.4}$$

Then Equation 6.3 becomes

$$\alpha'\beta\gamma = \alpha\beta'\gamma'. \tag{6.5}$$

This relation is special, and can not be reduced to the case in Galileo relativity by taking $c \to \infty$. That is to say, there exists one more symmetry or invariance beyond the relativity. We will show below this kind of symmetry is consistent with the method of QM.

In QM, there is no direct definition of velocity. However, we can introduce different states corresponding to different velocities. For example, if the velocity is v, the state can be labeled as $|v\rangle$, which is the eignstate of velocity operator. In Equation 6.2 there are three quantities, we view the velocity $\mathcal{V}_0$ as the velocity of another object M_C. Thus, the physical meaning of Equation 6.2 is that it demonstrates the correlations among the states of M_A, M_B, and M_C. The global state of them can be written as $|\psi\rangle$. Here, the state of M_A is $|-\mathcal{V}_A\rangle$, the state of M_B is $|\mathcal{V}_B\rangle$, the state of M_C is $|\mathcal{V}_0\rangle$, so

$$|\psi\rangle \equiv |-\mathcal{V}_A, \mathcal{V}_B, \mathcal{V}_0\rangle, \tag{6.6}$$

where the order of the objects is M_A, M_B, and M_C. The point here is we view the transition from v to -v as "time reversal" from t to "anti-time" τ as defined in Chapter 1, also shown in Figure 6.1. The anti-time has definite physical meaning. If the dynamics is invariant under time reversal, it means the dynamics is reversal. Let us apply time reversal to Equation 6.2, and we get

$$-\mathcal{V}_0 = \frac{-\mathcal{V}_B + \mathcal{V}_A}{1 - \mathcal{V}_B\mathcal{V}_A/c^2}. \tag{6.7}$$

The states of M_A, M_B, and M_C are $|\mathcal{V}_A\rangle$, $|-\mathcal{V}_B\rangle$, and $|-\mathcal{V}_0\rangle$, respectively. Thus, the global state is

$$|\phi\rangle \equiv |\mathcal{V}_A, -\mathcal{V}_B, -\mathcal{V}_0\rangle. \tag{6.8}$$

Equation 6.2 and Equation 6.7 are equivalent obviously, which means the two states $|\psi\rangle$ and $|\phi\rangle$ are equivalent. They form the maximally entangled state

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\psi\rangle - |\phi\rangle). \tag{6.9}$$

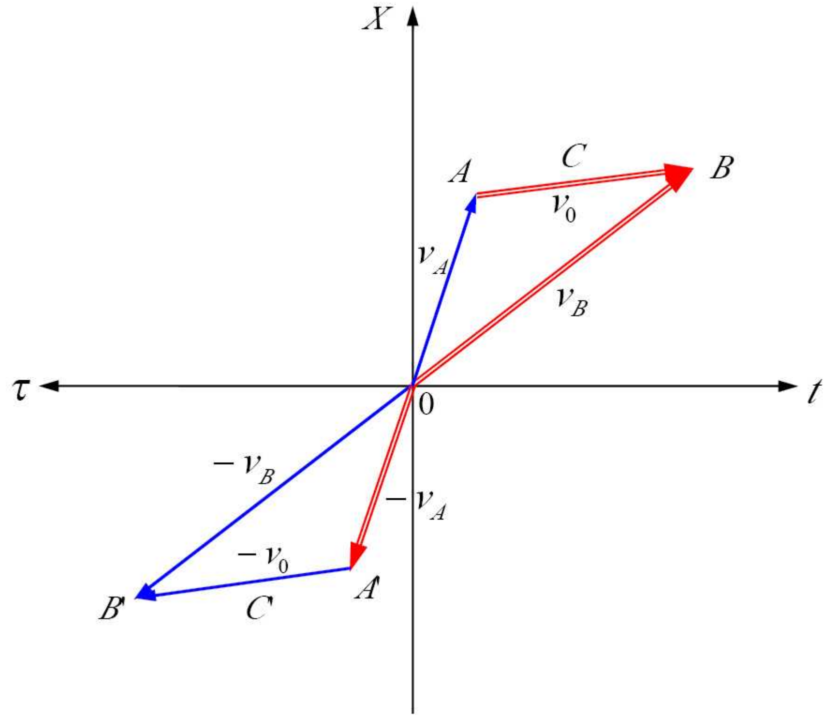


Figure 6.1: The unification of QM and Relativity. τ is "anti-time". In the anti-time region, the velocity is defined as $dx/d\tau$. The red arrows form the state $|\psi\rangle$, the blue arrows form the state $|\phi\rangle$. A, B, A', etc. are the relative motions, also we use velocity to stand for the relative motion.

.

In Figure 6.1, we illustrate the physical meaning of this entangled state. The red arrows represent $|\psi\rangle$, and the blue arrows represent $|\phi\rangle$, they have exchange asymmetry since they have phase difference π. When we apply time reversal, the time t becomes anti-time τ. Each branch $|\psi\rangle$ and $|\phi\rangle$ has three relative states. For example, the "time" state $|\mathcal{V}_A\rangle$, and the "anti-time" states $|-\mathcal{V}_B\rangle$ and $|-\mathcal{V}_0\rangle$ form the branch $|\psi\rangle$. In the global entangled state, the space-time is also entangled.

The equivalence of the two branches is also expressed in Equation 6.5. If we relate $\alpha = 1 - \mathcal{P}_A$ to state $|\mathcal{V}_A\rangle$, $\alpha' = 1 + \mathcal{P}_A$ to state $|-\mathcal{V}_A\rangle$, etc., then it means that Equation 6.5 describes the equivalence between $|\psi\rangle$ and $|\phi\rangle$. Actually, the quantities α, α', etc. have physical meanings. They measure the speed deviation from the speed of light. For instance, if $\mathcal{P}_A$ gets bigger, it means the "negative" deviation α gets smaller, while the "positive" deviation α' gets bigger. Physically, Equation 6.5 indicates that the speed deviation from c of the two branches $|\psi\rangle$ and $|\phi\rangle$ are the same.

To sum up, from SR, we know that there exist relativity and symmetry among the three relative motions; and from QM, we know that the states of the three motions form a special space-time entangled state. Thus, we show that the principle of superposition and entanglement is consistent with the principle of relativity, and there is no confliction between them. However, it does not mean there is no difference between them. Generally, they describe different properties of motion. In our model, SR mainly cares about the constraint of speed of light on the relative motions, while QM mainly cares about the correlations and symmetry among these relative states of motions. In addition, in our approach, we employ the time reversal to show the symmetry and demonstrate the physical meaning of anti-time.

However, frankly speaking, this approach can bring few new knowledge. We still rely on the principle of relativity and the principle of superposition and entanglement, no further reason is given. That is, we do not relate them with each other from a more fundamental view. We have to ask: does this fundamental view exist? Is their something more fundamental? We try to answer these questions in the next part of this chapter.

6.3 Beyond QM and Relativity

.

6.3.1 Absoluteness and Relativity of Motion (ARM)

.

From Relativity we can not be sure whether there is motion, whether an object is moving or not. This sounds quite dissatisfying. On the contrary, from thermodynamics (TD), we can be sure that for a closed system, the entropy increases, which is a real physical process. In principle, from the entropy, we can know whether there is motion. From this simple observation, we should re-consider what motion is, and, what "absolute" and "relative" really mean. We have studied this problem partly in Chapter 1, here we make a further analysis from the historical view.

The methods of *absoluteness and relativity of motion* (ARM), as well as time and space were firstly studied systematically by Aristotle [21]. He thought every object has the ability and propensity to move, that is to say, every motion is absolute, can not be viewed as fictitious. There both exist the absolute space and time, such as the background frame of the whole world and the change of the world, also the relative space and time, such as the place one object occupies and the age of one certain creature, respectively. Space and time in his view is connected with the ability of motion. However, this is basically qualitative. If we try to calculate, things may be different. One significant progress on the methods of ARM is made by Copernicus [22]. He found that earth is not the center of the universe, instead, earth moves around the sun together with several other planets. This revolution challenged the belief of the absoluteness of motion, which greatly promoted the development of physics. Newtonian Mechanics made the first unification of physics with the self-consistent dynamics [23].[7] From the first law of mechanics, the ability of motion is defined as "inertia", and force is the reason to change the motion. The mechanical motion seems quite "negative", it can not change until some force acts on it. The simplicity of Newtonian Mechanics also bases on the *absolute view of space and time* (AST). The motion of object is described as driven by force under the universal frame of space and time, which is different with Aristotle's description that the object moves due to its own force under its own space and time. However, parallel to Newton, Leibnitz held the opposite thought [24]. He viewed space and time as the relative properties of motion, different movements have different scales and properties of space and time, similar with Aristotle. As the AST developing, the opposite opinion is seldom held except some philosophers. For example, Kant criticized the AST in his fundamental antinomy [25], and later Engels viewed space and time as the properties of motion, instead of as some kind of entity [26]. The dissymmetry and tension between absoluteness and relativity gain some crisis at the end of 19th century. Poincaré claimed the non-measurability of the absolute motion, the motion of matter relative to ether, which indeed is a summary of the essence of the method of classical mechanics. And, in the SR of Einstein, time is external and spatialized as we have pointed out, and the space-time is still some entity.

Now if we focus our mind on the turn from Aristotle to Newton, we may ask: what is inertia? Is the ability of motion absolute or relative? If we can not be sure whether an object is moving according to SR, then, why the object has inertia? And, why the relative motion can be measured?

If these questions above can not be answered well by SR, then we may question the foundation of SR. Absolute motion, according to Poincaré, is defined as the motion relative to ether. In fact, this definition bases on one assumption: the matter and ether are different substance. However, from our study of ether (in chapter 7), matter is indeed a special state of ether, that is, they can not be viewed as different things. What's more, interestingly and fortunately, we can find a more reasonable definition of ARM based on the method of thermodynamics (TD).

In TD, the ARM has different meanings from Newton mechanics.[8] The common object in TD is the open system S, which has an "inner" structure and an "outside" environment E. Their are motions in the system, each motion can be denoted as m_r. The sum of these relative motions, labeled as $\sum m_r = M_r$, in the system is the inner motion of the system S, that is to say, this motion M_r is absolute relative to the system. Even if we do not know which part is moving, however, we are sure that there does exist motion. This absolute motion can only

[7] We should note that classical mechanics can not explain everything, it has special characters and limitation itself.

[8] This may be a reason that when TD was initially formed, it was viewed as incomplete.

be ignored when we consider the motion of the system S as a whole relative to another system, the outside environment E. From this analysis, we can form the definition of ARM as follows.

Definition 1. The relative inner motion m_r of a compound system S forms the absolute motion of the whole system:

$$\sum m_r|_S = M_r|_S \equiv M_a. \tag{6.10}$$

Here, $|_S$ means relative to the system itself, and below $|_E$ means relative to the environment. The definition of the transition between absoluteness and relative motions is as follows:

Definition 2. The motion of the system S with an absolute inner motion is relative to the other system, the outside environment E:

$$\sum m_r|_E = M_r|_E \equiv M_r. \tag{6.11}$$

Based on these definitions, we can deduce that when S and E are viewed as a whole $U = S + E$, then the relative motion of S and E form the absolute motion of U again. Generally, the absolute motion can be made of the relative motions as a whole, also the relative motion can be made of the absolute motions of many systems. Thus, there is no dissymmetry between absoluteness and relativity.

From the above definition, if we define absolute motion only relative to other outside things, such as ether, then we can not measure the absolute motion. Instead, if we define the absolute motion relative to the system itself, then there does exist motion when there are inner motions of the system. The reason that we can be sure there exists motion in the system is the *correlation* between them. If we view the system as a whole, then the objects of our research is not only the inner relative motions, but also the correlations C_r among them. Then, we can make the following definition:

Definition 3. The absolute motion of a system S is made of the relative motions of its inner parts and the correlations among them:

$$M_a \equiv M_r + C_r. \tag{6.12}$$

The inverse definition of definition 3 is that $M_r \equiv M_a - C_r$, which means the relative motion can be made of absolute motions of many systems when the correlations are ignored.

In all, on the study of ARM, we conclude that the starting point of Relativity is not proper or complete, in the sense that it breaks the relation between absoluteness and relativity. It is in TD that this relationship is maintained, mainly through the concept “correlation”. Also, in QM, we see the fundamental role of correlation.[9] Thus, we can consider whether we can make further step of our principle and improve Relativity.

6.3.2 Yiang, Space, and Time

.

From SR, we know that by ignoring correlation, space and time are viewed as the same thing. If SR is not complete, our view of space and time should eventually be changed. This should be a good thing since we can solve the dissymmetry and tension between absoluteness and relativity, and solve the problem of AST. Actually, we have answered this question in Chapter 1, that is, “yiang”, which lays the foundation of correlation and entanglement.

The main reason why there do exist correlations (entanglement or information) is that motions have the ability to correlate with each other. Newton Mechanics tells us that inertia is the ability for a certain object to move in space and time, while it does not describe correlations on a fundamental level. The concept “yiang” ensures correlations among motions have the same ontological meaning as motions themselves. The whole construction of the physics based on yiang is quite complex,[10] many basic methods and equations need to be re-formed and re-interpreted. Thus, for clarity, in this essay, we only present some primary discussions, the complete theory will be developed in the near future.

Before our analysis, there are several points to state. Firstly, in mathematical form, “spinor” is adopted to represent yiang.[11] Spinor, as well as twistor, have attracted physicists’ interest for a long time, such as [27]. However, at present, this kind of theory is mainly geometrical and not well-developed. There is no direct relation between spinor and yiang physically. Secondly, the well-known “spin” is a result of yiang, that is to say, spin is a special kind of effect of motion, also, spin belongs to every motion not only for the microscopic particles. Here we only point out this without demonstration, we may study it in detail elsewhere. Thirdly, we state again here we should restrain ourselves to the fundamental concepts instead of mathematics. Below, we will discuss the basic changes that yiang brings and the relation to the common methods.

For symmetry and conservation, Noether’s theorem states that any symmetry of the motion of a system has a corresponding conservation law [28]. As we all

[9]Here, we should make a distinction between interaction and correlation. Generally, the two methods come from different descriptions of motion. Interaction is needed to describe the casual dynamics, it should obey the law of causality. Correlation is mainly used to describe the statistical and systematical behaviors, it does not rely on the interactions among different systems. Nevertheless, they connect with each other without confliction.

[10]And honestly, I have not yet developed a well-formed theory at present. In Chapter 8, we name this theory as the “Tao-theory”.

[11]At present, no better form is discovered yet.

know, the conservation of energy corresponds to the time translation invariance, the conservation of momentum corresponds to the space translation invariance, as studied in Chapter 1. So, is' there some conserved quantity corresponding to yiang? The answer should be *yes*. It is information. Here we view information as a more basic concept than entropy and entanglement and also correlation. At present, entropy and entanglement are both used to describe information, also there is a difference between quantum and classical information, however, a well-developed information theory has not yet been achieved. Mathematically, yiang can be written as a vector with two components $\lambda = \begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix}$ (or more), correspondingly, information is written as a matrix $\mathbb{I}$.[12] There exist various representations which can transform to each other by unitary operator. Then, the quantity of information $\mathcal{I}$ is the observed value of $\mathbb{I}$ under a special representation, and it should be the same under different representations. This kind of invariance connects with some kind of conservation law. Thus, we can set up the law of conservation of information (LCI):

The information of a unique system is conserved. Information can transfer from one form to another, translate from one place to another, and the total amount is conserved.

Below we discuss this law from several aspects.

Firstly, there seems be an apparent confliction between LCI and the second law of thermodynamics (TD). However, this is not true. The second law of TD states that the entropy of a closed system has maximal value. This law relies on the method of entropy. However, as we studied in Chapter 4, entropy is not sufficient to quantify information. It mainly capture the global information of the system, while it cannot capture the inner local information within the system. Also, the methods "open" and "closed" are not concrete to describe information. One system can be open inside and closed as a whole as long as there exist information processes within. Further, from QM, we can use entanglement to describe information, too. It turns out that information and entropy are different physically, and entanglement show something more beyond entropy, which are often called "quantum". What is more, QM may lay the foundation of TD and develop a complete theory of information [29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40]. Although this is not finished, it is very promising. So, the second law of TD should not be accurate, and it is only the approximation of LCI. In addition, the second law has already been generalized in the research of dissipative system [41], and the total amount of entropy shows some character of conservation.

Secondly, as we have pointed out in Chapter 1, the conservation of informa-

[12] As it seems, the mathematics is quite similar with QM, however, the physical meaning is different.

tion is consistent with the conservation of energy and momentum. The reason is that the motion is unique.[13] As we know, there is one basic physical quantity *action*. Mathematically, action $\mathcal{A}$ can be expressed as Et, or $\mathbf{p} \cdot \mathbf{r}$. The properties of action are very interesting, to name a few, the action of a physical process is minimal, there is the uncertainty relation between E and t, $\mathbf{p}$ and $\mathbf{r}$ according to QM, the time (space) translation invariance connects with the conservation of energy (momentum). For information,[14] there should also be a quantity like action. Let us take entropy as an example. Entropy is often defined as $\mathcal{S} = Q/T$ or $\mathcal{S} = k_B \sum p_i \log p_i$, where Q is the energy, T is the temperature. Entropy has the same dimension as Boltzmann constant k_B. Further, taking the relation between time and temperature into account (as studied in Chapter 8), then entropy $\mathcal{S}$ has the same dimension as action $\mathcal{A}$, and there is an equivalence between Boltzmann constant k_B and Planck constant h.[15] Thus, there exists a one-to-one correspondence as the following table:

Table 6.2: Information, energy, and momentum.

attributes	observable	action
$\mathbf{r}$	$\mathbf{p}$	$\mathbf{p} \cdot \mathbf{r}$
t	E	E t
λ	$\mathbb{I}$	$\mathcal{I}$

Thirdly, although the three conservation laws have common properties, they are different. For example, long time ago, Leibniz had realized the difference between $\mathbf{v}$ (momentum) and v^2 (energy).[16] And, there exists one more conserved quantity based on momentum, that is, the angular momentum. Here, the new thing the LCI brings is *representation*, which is firstly discovered in QM. Representation is a method to describe relation. The special character of relation is there could be several kinds of relations between two motions. This is different with causality in dynamics. For the dynamics, there only exists one steady path at most

[13] Yet, this relies on our knowledge about the whole universe. If more and more energy are being generated, the laws of conservation then break. However, it is quite impossible for our human beings to observe and realize this kind of fact.

[14] At present, we have not found a concrete mathematical form of information.

[15] The connection between action and entropy had been realized by some people, such as de Broglie [42].

[16] In *Specimen Dynamicum* (1695), Leibniz developed the method "living force" which is twice the modern kinetic energy. Dynamism describes "monads" which have the essence of forces. It was developed as a reaction against the passive view of matter and the view of conservation of momentum.

with the least action. While there can be several parallel relations between two dynamics. The different relations, expressed as representations, can all describe the motion compatibly. The principle for representation, observable, and measurement is formed as the "complementary principle" according to QM. Also, the method of representation is different with the method of coordinate system. In classical mechanics, different coordinates are indeed the different mathematical expressions for the same dynamics and correlation. In contrast, different representations describe different relations, observable, measurements, and each representation can be expressed under several coordinates. The methods of information and yiang make representation have physical significance, different with the methods of space and coordinate.

Above, we have established the law of conservation of information (LCI) physically. Next, we study the relation between yiang and the principle of superposition and entanglement and the principle of relativity.

In QM, the principle of superposition and entanglement is just supposed. We have given a new interpretation based on the method of *scope* in Chapter 2 and 3. Based on our interpretation, QM sounds quite reasonable without any weirdness, and scope lays the starting point for a further complete form of QM. Here, the method of yiang is something beyond QM, that is, the physics of yiang (Tao-theory) is more fundamental than QM. The principle of superposition and entanglement is a direct result of yiang. Yiang means there exist correlations or coherence among different states within or beyond one scope. Thus, it is natural to form the superposed state and entangled state.[17]

Special Relativity (SR), as we all know, originates from the Maxwell equation and Galileo relativity. The validity of SR relies on the Maxwell equation, which describes the motion of particle with spin $\hbar$. However, seldom realized, there is a kind of mismatch between the method of Maxwell equation and Galileo relativity. In Galileo relativity, there are coordinate, velocity and time. This principle is indeed the same as the conservation of momentum. SR also satisfies the conservation of momentum. While, Maxwell equation bases on the method of energy, there are amplitude and c^2 in this equation. The fact there exists c^2 instead of c is important in a fundamental sense, since velocity $\mathbf{v}$ and its square v^2 (or $|v|^2$ with $v = v_1 + iv_2$) have different physical essence [43]. Based on this observation, the meaning of Lorenze transformation (LT) should be re-interpreted, and also the foundation of SR: the non-measurability of the absolute motion. According to our study of ARM in the last part, the methods "absoluteness" and "relativity" adopted in SR are not proper. Instead, we should describe the motion based on correlation (or relation, entanglement). The consistency of the speed of light means every motion exists in the same field (ether) instead of empty space. Further, in order to re-construct the meaning of LT, we introduce the method of *action rate* $\eta = v^2$ (or *relative action rate* $\eta' = v^2/c^2$), which is different with velocity, it can

[17]In addition, for the relation between scope and yiang, we do not intend to discuss here.

not be expressed as $v^2 = x^2/t^2$. Also, it is consistent with the method of "speed weight" in the former section. The action rate means the ability of one motion to induce the correlation to another motion. For example, when $\eta = c^2$, it means everything becomes field, which is a most coherent and correlated entity. Also, we refer to the physical picture of "hidden dynamics" in QM [44, 45, 46], that is, there is one field corresponding to one object. However, here, the field is not the "matter wave", instead, it is the ether surrounding the object. Ether serves as the fundamental environment of one object and provides the correlations between two objects. Then, mathematically, in coordinate representation, the yiang of the objects A and B can be expressed as

$$\begin{aligned} \lambda_A &= \begin{pmatrix} \mathcal{F}(x) \\ \mathcal{F}(ct) \end{pmatrix} = \mathcal{F} \begin{pmatrix} x \\ ct \end{pmatrix}, \\ \lambda_B &= \begin{pmatrix} \mathcal{F}(x') \\ \mathcal{F}(ct') \end{pmatrix} = \mathcal{F} \begin{pmatrix} x' \\ ct' \end{pmatrix}, \end{aligned} \tag{6.13}$$

where $\mathcal{F}$ is a certain function relating yiang λ to space x and ct (so time t). Following the same procedure of common SR, it is straight forward to get the transformation similar with the LT as follows

$$\begin{pmatrix} x' \\ ct' \end{pmatrix} = \mathcal{F}^{-1} \mathcal{W} \mathcal{F} \begin{pmatrix} x \\ ct \end{pmatrix}, \tag{6.14}$$

where the matrix $\mathcal{W}$ is

$$\mathcal{W} = \gamma \begin{pmatrix} 1 & -\sqrt{\eta'} \\ -\sqrt{\eta'} & 1 \end{pmatrix}, \tag{6.15}$$

with $\gamma = 1/\sqrt{1-\eta'}$, the function (operator) $\mathcal{F}$ satisfies $\mathcal{F}\mathcal{W} = \mathcal{W}\mathcal{F}$. When $\eta' \to 0$, $\gamma \to 1$, $\mathcal{W}$ becomes the identity matrix.

This is the modified LT. It is easy to deduce the usual LT

$$\begin{pmatrix} x' \\ t' \end{pmatrix} = \gamma \begin{pmatrix} 1 & -v\gamma \\ -v\gamma/c^2 & 1 \end{pmatrix} \begin{pmatrix} x \\ t \end{pmatrix}. \tag{6.16}$$

The physical meaning of the modified LT is clear. When the (relative) action rate is small, the motion of one object seldom affect the surrounding field, thus, there is no correlation and coherence between the two objects. However, when the action rate gets bigger, the $\mathcal{W}$ matrix changes from identity matrix to non-diagonal matrix, the coherence within is activated and the two objects are correlated, with the maximal action rate c^2. The meaning of $\mathcal{W}$ matrix is that there exist coherence (or covariant coherence, not the same with that in QM) between the two motions λ_A and λ_B. For time and space, of course, they are correlated together. However, it does not mean time and space form the space-time matric, and they themselves do not have independent meanings. In fact, the modified LT mainly describe the coherent relation between two yiang, time and space are independent parameters. Generally, SR indicates there exists coherence induced by the action rate between two yiang. We can view SR as a theory of time and space, even we can view it as the demonstration of causality, however, it is much more than that.[18]

In all, the investigation above gives a short introduction of the Tao-theory and the physical meaning of yiang.[19] We have discussed a little about yiang in Chapter 1, and we will discuss a little more in Chapter 8.

In conclusion, in this chapter, we studied the foundation of QM and SR, both of which need to be re-interpreted. At the early days, the two theories seldom relate with each other, and sometimes (even till now) conflict with each other. However, as we demonstrate in a primary but fundamental way, QM and SR is consistent with each other and can be built on the same cornerstone.

[18]For causality, we do not intend to discuss it in detail. One may interested in the critics of causality, please read Ref. **??**.

[19]One may find that the mathematics is quite easy. While, it is not true. Here, we only focus on the basic methods different with the common interpretation, the mathematics such as spinor, also the dynamics are quite complex and abstract.

Bibliography

[1] C. Harding, *Quantum Mechanics as Demanded by the Special Theory of Relativity*, Found. Phys. **7**, 69-76 (1977).

[2] N. Maxwell, *Instead of Particles and Fields: A Micro Realistic Quantum "Smearon" Theory*, Found. Phys. **12**, 607-631 (1982).

[3] E. Prugovcki, *The Stochastic Quantum Mechanics Approach to the Unification of Relativity and Quantum Theory*, Found. Phys. **14**, 1147-1162 (1984).

[4] R. Schlegel, *An Interaction Interpretation of Special Relativity Theory*, Found. Phys. **3**, 169-184 (1973), part I; **3**, 277-295 (1973), part II; **5**, 197-215 (1975), part III.

[5] M. H. MacGregor, *Generalizatioin of the Postulates of Special Relativity*, LETTERE AL NUOVO CIMENTO **43**, 49-54 (1985).

[6] Dynamics of Pure Shape: J. Barbour, B. Z. Foster and N. Ó Murchadha: Class. Quant. Grav. **19**, 3217 (2002); *Relativity without relativity*, gr-qc/0012089 11; E. Anderson and J. Barbour: Class. Quant. Grav. **19**, 3249 (2002); *Interacting vector fields in relativity without relativity*, gr-qc/0201092 12.

[7] O. Darrigol, *The Genesis of the Theory of Relativity*, Birkhäuser Verlag, Basel, 2005.

[8] K. Brown, *Reflections on Relativity* (http://www.mathpages.com/rr/rrtoc.htm).

[9] S. Katzir, *Poincaré's Relativistic Physics: Its Origins and Nature*, Phys. perspect. **7**, 268-292 (2005), and references therein.

[10] E. Mach, *Die Mechanik in ihrer Entwicklung historisch-kritsch dargestellt*, (Barth, Leipzig 1883); *The Science of Mechanics*, (Open Court, Chicago 1893).

[11] H. Poincaré, *A propos de la théorie de M. Larmor*, *L'Eclairage électrique* **5** (October 5, 1895), 5-14; reprinted in *OEuvres de Henri Poincaré*, Vol. 9 (Paris: Gauthier-Villars, 1954), pp. 395-426; quotation on p. 412.

[12] H. Poincaré, *La Théorie de Lorentz et le Principe de Ráction*, *Archives néerlandaises des Sciences exactes et naturelles*, **5** 252-278 (1900).

[13] H. Poincaré, *La mesure du temps*, in *La Valeur de la Science* (Paris: Ernest Flammarion, 1970), pp. 41-54; translated by George Bruce Halsted as *The Measure of Time*, in *The Value of Science*, pp. 223-234.

[14] H. Poincaré, *Sur la dynamique de l'électron*, *Comptesrendus hebdomadaries des séances de l'Académie des Sciences*, **140** 1504-1508 (1905); *Sur la dynamique de l'électron*, *Rendiconti del Circolo matematico di Palermo*, **21** 129-176 (1906).

[15] E. T. Whittaker, *A History of the Theories of Aether and Electricity.* Vol. 2. *The Modern Theories* (New York:Tomash Publishers and American Institute of Physics, 1987), pp. 27-77.

[16] H. Poincaré, *Science et méthode*, (Paris: Ernest Flammarion, 1947), p. 100; translated by George Bruce Halsted as *Science and Method* in *Foundations of Science*, pp. 359-546; on p.416.

[17] H. Poincaré, *Science et l'Hypothése*, pp. 245-246; *Science and Hypothesis*, p. 174.

[18] H. A. Lorentz, *Electromagnetic phenomena in a system moving with any velocity smaller than that of light*, *Koninklijke Akademie van Wetenschappen te Amsterdam. Proceeding of the Section of Sciences*, **6** 809-831 (1904); reprinted in Collected Papers, Vol. 5 (The Hague: Martinus Nijhoff, 1937), pp. 172-197.

[19] H. A. Lorentz, *The Theory of Electrons and its Applications to the Phenomena of Light and Radiant Heat* (Leipzig: B.G.Teubner, 1909; second edition, 1916).

[20] H. Minkowski, *Space and Time*, in *The Principle of Relativity*, (Dover, New York), p. 87.

[21] Aristotle, *Metaphysics* (Oxford, Clarendon Press, 2006).

[22] N. Copernicus, *On the Revolutions of the Heavenly Bodies*, translated by E. Rosen, (London: Macmillan, 1972).

[23] I. Newton, *Mathematical principles of natural philosophy* (Berkeley: Univ. of California Pr., 1999).

[24] G. W. Leibniz, *New essays concerning human understanding* (The Open Court Publishing Company, Chicago *etc.*, 1916).

[25] I. Kant, *Critique of Pure Reason* (China Social Sciences Pub. House, Beijing, 1999).

[26] Engels, *Dialektik der Natur*, translated as *Natural Dialectics*. Also S. E. Stumpf and J. Fieser, *A history of philosophy* (Peking University Press, Beijing, 2006).

[27] R. Penrose and W. Rindler, *Spinsors and space-time* (Cambridge monographs on mathematical physics, reprint. Originally published: Cambridge, U.K. : Cambridge University Press, 1984-1986. 9780521337076 (v. 1) 9780521347860 (v. 2)).

[28] E. Noether, *Invariant Variation Problems* arXiv:physics/0503066v1 [physics.hist-ph] 8 Mar 2005.

[29] S. Popescu and D. Rohrlich, *Thermodynamics and the measure of entanglement*, Phys. Rev. A **56**, R3319 (1997).

[30] S. Popescu, A. J. Short, and A. Winter, *The foundations of statistical mechanics from entanglement: Individual states vs. averages*, arXiv:quant-ph/0511225v3.

[31] R. Horodecki, M. Horodecki, and P. Horodecki, *Balance of information in bipartite quantum-communication systems: Entanglement-energy analogy*, Phys. Rev. A **63**, 022310 (2001).

[32] M. Horodecki, J. Oppenheim, and K. Horodecki, *Are the Laws of Entanglement Theory Thermodynamical?*, Phys. Rev. Lett. **89**, 240403 (2002).

[33] J. Oppenheim, M. Horodecki, P. Horodecki, and R. Horodecki, *Thermodynamical Approach to Quantifying Quantum Correlations*, Phys. Rev. Lett. **89**, 189402 (2002).

[34] M. Horodecki, P. Horodecki, and J. Oppenheim, *Reversible transformations from pure to mixed states and the unique measure of information*, Phys. Rev. A **67**, 062104 (2003).

[35] M. Horodecki, *Reversible path to thermodynamics*, Nature Phys. **4**, 833 (2008).

[36] F. G. S. L. Brandão and M. B. Plenio, *Entanglement theory and the second law of thermodynamics*, Nature Phys. **4**, 873 (2008).

[37] F. G. S. L. Brandão and M. B. Plenio, *A Reversible Theory of Entanglement and its Relation to the Second Law*, Commun. Math. Phys. **295**, 829-851 (2010).

[38] V. Scarani, M. Ziman, P. Štelmachovič, N. Gisin, and V. Bužek, *Thermalizing Quantum Machines: Dissipation and Entanglement*, Phys. Rev. Lett. **88**, 097905 (2002).

[39] D. Jou and José Casas-Vázquez, *About some current frontiers of the second law*, Journal of Non-Equilibrium Thermodynamics **29**, 345 (2004).

[40] D. Jennings and T. Rudolph, *Entanglement and the thermodynamic arrow of time*, Phys. Rev. E **81**, 061130 (2010).

[41] I. Prigogine and I. Stengers, *Order out of Chaos* (Bantam Books Inc., 1984).

[42] L. de Broglie, *The Reinterpretation of Wave Mechanics*, Found. Phys, **1**, 5-15 (1970).

[43] C. Stott, *A New Dynamism for Philosophy*, http://www.philosophy-dynamism.co.uk/. Also, Leibniz, *Specimen Dynamicum* (1695).

[44] L. de Broglie, *An Introduction to the Study of Wave Mechanics* (E. P. Dutton and Co., New York, 1930).

[45] D. Bohm, *A suggested interpretation of the quantum theory in terms of "hidden variables"*, I and II, Phys. Rev. **85**, 166-193 (1952).

[46] J. G. Cramer: *The transactional interpretation of quantum mechanics*, Rev. Mod. Phys. **58**, 647-688 (1986).

[47] D. Hume, *A treatise of human nature* (China Social Sciences Pub. House, Beijing, 1999).

Chapter 7

AETHER

7.1 Historical view

.

Aether (ether) is a very old concept to stand for the very fundamental element of the matter of the whole universe. It is in 19th century that the theory of ether was greatly developed, while in 20th century the crisis and "death" of ether happened. The ignorance of the existence of ether seems very strange compared to such a long history of its existence.

The problem of ether usually connects with the theory of Relativity, light, and space. In this chapter, we take the grand view of "the physics of ether" to look at the relation between them. Before the following quite long journey, we first state that we will prove that ether does exist.

At Newton's age, the concepts "light" and "ether" both exist. Newton viewed light as kind of micro-particle [1]. However, this can not explain the reflection and diffraction phenomenon. So, Newton attributed the reason to some ethereal medium. But, Newton did not form a complete theory of ether. In addition, Newton believed the absolute space, however, the relation between space and ether was not clear.

Huygens and Fresnel set the wave theory of light, which claimed that light is the transverse wave propagating in ether. At this time, physicists began to widely study the mechanical properties of ether. For example, Cauchy and Stokes suggested the famous "dragging" [2].

About a half a century later, Maxwell also believed that ether is the medium of light propagation. We should pay attention to that when light is viewed as wave instead of particle, the problem of ether and space is not so important, since light is a kind of wave movement in ether. It is ether that occupies the space not light. What Maxwell does is significant: he proved that light is a kind of electro-magnetical wave, thus unifying optics and electromagnetics, also the mechanical, optical, and electrical properties of ether. Besides his famous equation of field, he formed the electromagnetic dynamics, which is the mechanical model of ether with wheels and gears. The molecular vortices used to explain the magnetic lines are composed with both ether and ordering matter [3]. Unfortunately, this dynamics is not very convincing. At that time, various dynamics of ether were formed, such as the notable work of Lord Kelvin.

In another way, during the whole 19th century, experiments never ceased to test the "dragging", however, almost all of them got null result. At the end of 19th century and the beginning of the 20th century, the ether fell into crisis, as Kelvin described as one "frog".

The situation is that physics was facing some kind of "impossible". Poincaré realized the impossible to detect the absolute motion, that is, the movement of matter relative to ether, and started to work on the principle of Relativity [4]. Lorenze surpassed the problems of Maxwell's dynamics based on his electron theory [5]. He separated ether and electron apart and set ether as the absolute steady frame, and the interactions between electrons transpose in ether. Eventually, the *Lorenze ether theory*, also Poincaré's *Postulate of Relativity* could well solve the problem facing by ether. However, at that time, physicists, for example, Planck, Lauc, Hirbert, Langivin still held different attitudes towards the existence of ether. Poincaré did not deny the existence of ether, he thought it is a conventional concept to help to set up the fundamental principle. Lorenze believed the existence of ether. It is Einstein who definitely denied the existence of ether [6, 7].

We have pointed out that Einstein's SR is kinematic, based on space and time, and space-time (Minkowski) is like the rigid body, that is to say, at that time, Einstein believed their exists empty space. He stated that our institution of space comes from the concept of matter and the connection of different bodies. Thus ether is redundant. As he described in 1920, the electromagnetic field is a finial fundamental entity, to suppose the existence of a kind of isotropic, homogeneous ethereal medium, to which electromagnetic field is viewed as the state, is not necessary [8]. The point is Einstein viewed electromagnetic field, or the "photon" he invented, as a kind of unique matter. As he himself described, this is the revival of the particle theory of light of Newton. However, photon has very strange property, such as, it has zero stationary mass, and it is wave-particle like. But the quantum theory of light during the "Old Quantum Age" proved to be successful, photon then was adopted by physicists. This should be viewed as the success of the world view of electromagnetism to the classical mechanical world view.

One of Einstein's reason to abandon ether is the conflict between the Lorenze theory (original) and the principle of relativity as he thought. He found that, if the frame S is steady relative to ether, other frame S' is moving with relative velocity v to ether, then, according to the principle of relativity, it is also right to suppose S' is steady, and S is with velocity. There are confliction between Lorenze theory and relativity on the symmetry between S and S'. Thus, Einstein abandoned the ether [6].

In fact, however, we can find some flaw in Einstein's argument. There's no need to introduce the frame of ether, what are needed are only the two inertia frames. Also, in principle, to say "a steady frame relative to ether" is wrong, since there is no way to decide whether an inertia frame is moving or not. In contrast, Poincaré did not view ether as the absolute frame, thus their is no need to deny the existence of ether.

Initially, the abandon of ether is the key character of Einstein's relativity, while in the following years, Einstein changed his mind a little. In 1920, he stated that the hypothesis of ether is not in conflict with SR as long as we attribute no state of motion to ether. He viewed ether as the $4-D$ space-time matric. Further, he stated that general relativity (GR) endows space with physical quantities, thus ether can be viewed as the gravitational field as the space-time matric, but "no substance or state of motion can attributed to ether" [8]. This time, he connected ether with the field theory which should have some value for the modern quantum field theory (QFT). However, ether is still viewed as the space-time frames without any dynamics or state of motion. This is the result of the fact that Einstein viewed space-time as entity instead of the property of motion, as we have discussed.

In all, from the above study we claim that we can not prove the existence or non-existence of ether. Since people view field as a kind of matter, ether is buried down. As the development of QM and QFT, the theory of ether died. Since the great power of quantum theory, there is no need to form the ether dynamics. Seldom scientist talked about ether except some historians, but the problem of ether still exist: we still can not prove whether ether exists or not.

7.2 Modern view

.

What is well mentioning is that in 1951, Dirac took the step to form a certain quantum field theory to support ether. He said that "If one re-examine the question in the light of present-day knowledge, one finds that the ether is no longer ruled out by relativity. [9]" Another big thing is in 1953, Whittaker published the second addition of his notable book: *A History of the Theory of Aether and Electron* [10]. In this book, he questioned lots of conventions of the development of physics in the early 20th century. For example, he wrote that Einstein "set forth the relativity theory of Poincaré and Lorenze with some amplifications and which attracted much attention." And Whittaker thought vacuum is just the ether.

After the set up of the QFT [11], there is a tendency to re-examine some basis concepts [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25], ether is one of them. Actually, if we reconsider the problem of ether from modern quantum field theory, we can get the conclusion that ether exists, and it has another improper name: the vacuum.

Let us explain what is vacuum. First, the concept "vacuum" is connected with "space". During the development of thermodynamics, vacuum is proved to exist as "empty space", thus it is also a kind of entity. This empty vacuum is inherited in quantum field theory. Now, nobody view vacuum as empty space, since according to our theory, vacuum is the ground state as the zero-point energy. There are fluctuational virtual process in the vacuum. Also, there are phenomenons, such as Casimir effect, Lamb shift, cosmological constant [26], to prove its existence and property. If, we turn our head to check Poincaré's principle of relativity, we can find the essence of ether. Firstly, Poincaré's principle only state that the relative motions of matter to ether is not detectable "with the coordinate frame method". The frame method this principle adopts plays a fundamental rule. Actually, in QM and QFT, there is no definite description of reference frame. In QM, motion is described as uncertain with randomness. For a random process, it is possible to manifest fluctuation without measurable average velocity, that is $\langle v \rangle = 0$, $\langle v^2 \rangle \neq 0$. So, it is impossible to test the so-called "dragging". What we get from QFT is just the energy, fluctuation etc., instead of velocity. The Casimir effect etc. just manifest that the effect of the vacuum (ether) can be detected, only in the sense different from Poincaré's relativity, there is no conflict between them. On the contrary, they describe different aspects of ether. Secondly, "vacuum" in QFT is not "real empty space", actually, it is filled with photons. Thus, it is reasonable to view field as the excited motion of ether, photons propagate in the medium of ether, just as Fresnel thought several hundred years ago. The only difference is that the dynamics of ether is not the same as viewed by Fresnel, Stokes, Maxwell, Kelvin etc.. Also from QFT, matter is also the excited state of field. From this point, we can see the old question "does ether moves with matter together?" is not proper, since everything is a kind of excited state of ether. Thirdly, it is possible to construct a kind of ether dynamics with the help of QFT, as inspired by Dirac. For example, in the stochastic model, the energy of ether is considered conserved, while the momentum can be changed [15]. This is accordance with SR in which the momentum is also not conserved. The effort along this spirit are still going nowadays [15, 19, 22]. Forth, in GR, space-time is still viewed as some entity instead of the property of motion, thus, it also face the problems, such as "what is in the empty space-time?","where is the space-time?" It is also possible to introduce some ether-like particle to substitute the non-Euclidian space-time matric. If we view all the universe is filled with ether, and space-time is the property of its dynamics, it is also a very beautiful world view.

In all, from our study, we know, that the temporary abandon of ether is due to this simple fact: to test its existence, wrong theories and wrong experiments are employed, then wrong conclusion is drawn. And further the long time death of ether is also due to one simple fact: there is no need to care about a dead thing as long as we have a seemingly better method to use: the QFT. It turns out to me that not only the universe is filled with ether, exactly, the universe as a whole is made of ether, since matter is considered as the excited state of field. Everything is in ether. Our physical world and theory can be unified based on ether. This seems far-more uncertain, however, the revival of ether is expected.

Bibliography

[1] I. Newton, *Opticks: or, A treatise of the reflections, refractions, inflections and colours of light* (Printed for William Innys at the West-End of St. Paul's., 1730).

[2] From Wikipedia: *History of Optics* (http://en.wikipedia.org/wiki/History of optics).

[3] J. C. Maxwell, *A dynamical theory of the electromagnetic field* (1865).

[4] H. Poincaré, *A propos de la théorie de M. Larmor*, *L'Eclairage électrique* **5** (October 5, 1895), 5-14; reprinted in *OEuvres de Henri Poincaré*, Vol. 9 (Paris: Gauthier-Villars, 1954), pp. 395-426; quotation on p. 412.

[5] H. A. Lorentz, *Electromagnetic phenomena in a system moving with any velocity smaller than that of light*, *Koninklijke Akademie van Wetenschappen te Amsterdam. Proceeding of the Section of Sciences*, **6** 809-831 (1904); reprinted in Collected Papers, Vol. 5 (The Hague: Martinus Nijhoff, 1937), pp. 172-197.

[6] A. Einstein, *Über die neueren Umwandlungen, welche unsere Anschauungen uber die Natur des Lichtes erfahren haben*, Deutsche Physikalische Gesellschaft, Verhandlungen **7** 482-500, 30 October, 1909.

[7] A. Einstein, *Fundamental Ideas and Problems of the Theory of Relativity*, Nobel Lectures, Physics **11**, 1901-1921 (1923), Amsterdam: Elsevier Publishing Company, http://nobelprize.org/nobel prizes/physics/laureates/1921/einstein-lecture.pdf, retrieved, 25 March, 2007.

[8] A. Einstein, *Aether and Relativity*, report at State University of Leiden, Netherlands, 5 May, 1920.

[9] P. A. M. Dirac, *Is there an aether?*, Nature **24**, 906 (1951).

[10] E. T. Whittaker, *A History of the Theories of Aether and Electricity*. Vol. 2. *The Modern Theories* (New York:Tomash Publishers and American Institute of Physics, 1987), pp. 27-77.

[11] P. A. M. Dirac: *Lectures on Quantum Mechanics* (Yeshiva University, New York 1964).

[12] L. Jánossy, *A New Approach to the Theory of Relativity. III. Problem of the Ether*, Found. Phys. **2**, 9-25 (1972).

[13] Bryan G. Wallace, *The Unified Quantum Electrodynamic Ether*, Found. Phys. **3**, 381-388 (1973).

[14] K. P. Sinha, C. Sivaram, and E. C. G. Sudarshan, *Aether as a Superfluid State of Particle-Antiparticle Pairs*, Found. Phys. **6**, 65-70 (1976).

[15] N. C. Petroni and J. P. Vigier, *Dirac's Aether in Relativistic Quantum Mechanics*, Found. Phys. **13**, 253-286 (1983).

[16] M. H. MacGtegor, *A Dynamical Basis for the de Broglie Phase Wave*, LETTERE AL NIJOVO CIMEITO **44**, (1985).

[17] F. Winterberg, *Derivation of Quantum Mechanics from the Boltzmann Equation for the Planck Aether*, Int. J. Theor. Phys. **34** 2145-2164 (1995).

[18] F. Winterberg, *Equivalence and Gauge in the Planck-Scale Aether model*, Found. Phys. **34**, 265-285 (1995).

[19] N. C. Petroni and F. Guerra, *Quantum Mechanical States as Attractors for Nelson Processes*, Found. Phys. **25**, 297-315 (1995).

[20] R. Tomaschitz, *Cosmic Ether*, Int. J. Theor. Phys. **37** 1121-1139 (1998).

[21] C. H. Brans, *Absolute Spacetime: The Twentieth Century Ether*, General Relativity and Gravitation **31**, 597-607 (1999).

[22] N. C. Petroni, *Stochastic collective dynamics of charged-particle beams in the stability regime*, Phys. Rev. E **63**, 016501 (2000).

[23] T. Jacobson and D. Mattingly, *Gravity with a dynamical preferred frame*, Phys. Rev. D **64**, 024028 (2001).

[24] D. Meschini and M. Lehto, *Is Empty Spacetime a Physical Thing?*, Found. Phys. **36**, 1193-1216 (2006).

[25] M Gürses, *Gödel type metrics in Einstein-aether theory*, Gen Relativ Gravit **41**, 31-38 (2009).

[26] R. L. Jaffe, *The Casimir Effect and the Quantum Vacuum* (http://arxiv.org/abs/hep-th/0503158v1).

Chapter 8

Unified Physics and Nature

Philosophers and scientists belief that nature is unified and harmonious. The principles discovered by physicists demonstrate the ability of human beings and the mystery of the universe. The dream of a unified physics has always been realized in the history and it yet always is proven to be only partly unified. In our century, after the efforts of Albert Einstein, Steven Weinberg, Edward Witten, etc., the dream still remains. Is it possible to take some certain step to get close to the unified physics? It is a great pleasure to think about it, and in this last chapter, we discuss from three aspects. Firstly, let us look at Figure 8.1 (also we can refer to Chapter 1). In this figure, CM stands for the classical mechanics including Relativity, QM stands for quantum mechanics, TD stands for thermodynamics and statistical physics, QFT stands for quantum field theory, M stands for the M-theory, and ? stands for some unknown physics. The arrows ($i \to j$) stand that j is the foundation of i.

8.1 QM lays the Foundation of TD

.

It has been proven that CM lays the foundation of TD. From the causal dynamics of particles, such as molecule, the laws of TD can be derived.

From the superposition and entanglement principle which characterize the correlations, the statistical properties can also been derived. Yet, this unification has not been well established.

CM and QM are different descriptions, the former one describes the individual, dynamical aspects of the motion, the later one describes the systematical, relational aspects of the motion. For a unique motion, both aspects exist. Strictly, motion has three primary attributes: continuity, extensivity, and integrity (see Chapter 1).

Although we can lay foundation of TD both on CM and QM, however, this does not mean that TD is not one fundamental description of motion. This is due to the law of "emergence", which states that the laws of nature are not totally reducible. In TD, entropy and temperature are basic concepts in physics.

From QFT, the basic property of the motion of field is fluctuation, to characterize it, TD is needed.

QFT is a direct generalization of QM. However, at present, due to the confusion of QM itself, the meaning of "quantum" in QFT is also unclear.

The fundamental part of QFT from CM is mainly Relativity, that is, the limit speed of field in vacuum is constant and the principle of general covariance.

The same with TD, QFT is also one basic description of motion. According to our interpretation, the elementary object QFT describes should be the nonseparable ether. QFT without a complete description of ether should not be viewed as complete. More efforts are needed to complete QFT, the same with QM.

8.2 $t - T$

.

Time is the timeless mystery of physics. It is fortunately enough for Mathematics to avoid the torture of time. At present, there are several meanings of time in physics. In CM and QM, time t is the frame of dynamics, which is universal and *a priori gegeben*. In Relativity, t is spatialized to form the space-time matric, t can be affected by motion, however, it loses its independence. In TD, t has "arrow", that is, t has the internal characters of motion. In fact, entropy is the inherent time of a certain motion. The inherent time is a consequence of motion, not *a priori*. In QFT also quantum cosmology, the meaning of time is a jumble at present, see Ref. [1, 2, 3] for example. It has been for ages the time to clarify the meaning of t in physics.

We have discussed the relation between time t and entropy S, the structure of time in Chapter 1, in this chapter, we should demonstrate again that we should pay attention to the meaning of time in our theory and equations under different situations.

Further, we point out that temperature T has a close relation with time t. Both of them can be viewed as the consequence of emergence. The third law of TD states that the absolute zero can not be reached, that is, a physical state without T is forbidden. Also, the first law of Newton mechanics states that an object stays or moves with constant velocity without the disturbance of other force. However, there is no isolated object in reality, thus, every motion has certain force. If we view time t as inherent property of motion, then, every motion has a t. The reality of T and t means that any motion of an object can not be isolated from the outside world. It is the connections among different objects that ensure the reality of T and t.[1] Mathematically, according to QM, the evolution operator is $e^{-i\mathcal{H}t/\hbar}$,

[1] This is in accordance with Mach's principle, also the principle of the coherence of the universe,

which generates a phase on the quantum state. According to TD, in Boltzmann distribution, there is a dissipative factor $e^{-\mathcal{H}'/kT}$, which describes the openness of a state. Introducing a complex parameter $\tau \equiv it + 1/T$, or we can let $1/T \equiv f$, which describing the "laziness" of the state, then, $\tau = it + f$. The basic operator on a general state should be $e^{\mathcal{H}_0 \tau}$, where $\mathcal{H}_0 \equiv \mathcal{H}/\hbar \equiv \mathcal{H}'/k$. From this operator, it is possible to study the connection between T and t, and also the connection between TD and QM. This is left an interesting open problem.

8.3 $t - \lambda - \mathbf{r}$

.

The three fundamental attributes of motion should be described within a unique theory, we can term it as the theory of *Tao*, which is the fundamental principle of the universe founded by the Chinese philosopher Lao-tzu. If there is the theory, and if we can reach it, the fundamental principle of nature should be bright and clear for our human beings.

The Tao-theory is not the same with the M-theory. In M-theory, one of the basic issue is the unification of fields. In a way, M-theory is a generalization and completion of QFT. It is possible that even when we set up the M-theory eventually, the fundamental attributes of motion could still be vague, since it is not directly based on the attributes of motion.

The basic object in Tao-theory should be ether, and the parameters t, λ, $\mathbf{r}$, also λ^*, $\mathbf{r}^*$ (totally 11 parameters), are needed, and also several basic constants, such as h and c, are needed to form the equation of dynamics of ether. And, we state that at the fundamental level, there should be several connected properties of motion, which generate the basic constants, instead of only one property. These co-exist properties and co-exist principles work together without confliction. Also, every principle is universal, such as the energy conservation principle, the superposition principle, the relativity principle, that is to say, the physical world is not divided into several regains, in which a certain principle domains. Thus, the quantum world is not only limited in the microscopic scale, the gravity also has effects in the microscopic scale. The universe is a coherent entity, there is no boundary within it for different principles, the boundary and role of the principles is only that they should connect with each other in harmony. Indeed, the harmony of the universe has always been realized by people, such as Pythagoras, Kepler, Leibniz, Einstein. For clarity, we can form this as a certain principle itself: the principle of harmony of the principles of the universe (PHPU):

The principles of universe are universal, can not be limited by any factors, connect with each other in harmony, and form the harmony universe.

---

see Chapter 4.

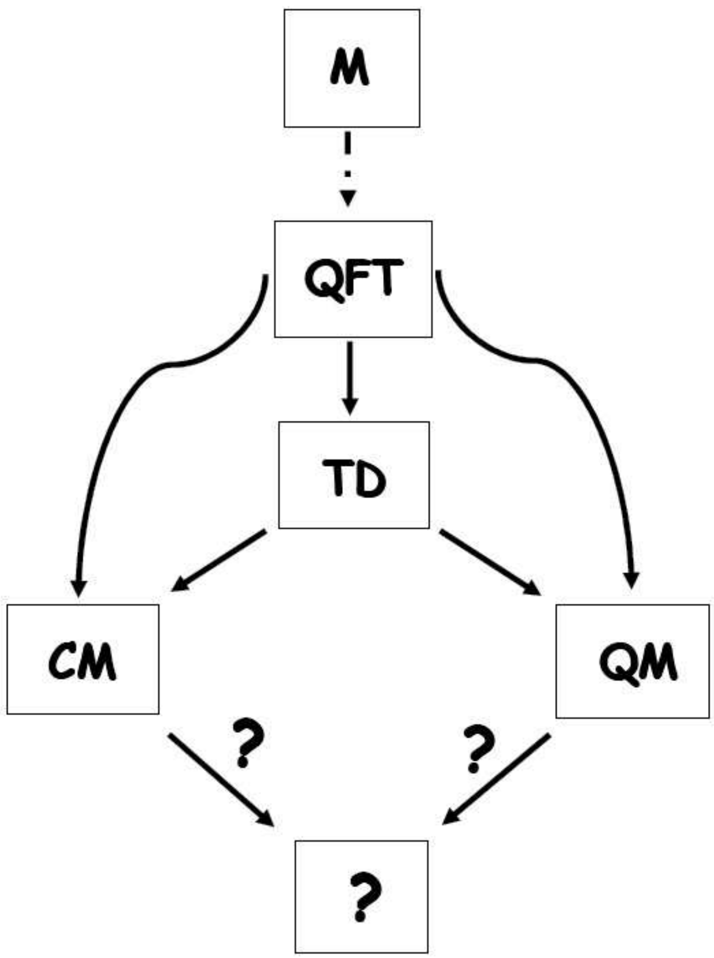


Figure 8.1: The unified physics.

Bibliography

[1] L. Smolin, *The present moment in quantum cosmology: Challenges to the arguments for the elimination of time* (arXiv:gr-qc/0104097v1 29 Apr 2001).

[2] C. Rovelli, *"Forget time"* (arXiv:0903.3832v3 [gr-qc] 27 Mar 2009).

[3] H. D. Zeh: *The Physical Basis of the Direction of Time* (the 5th edition, Springer, Berlin 2007).