Quantum Equivalence Principle In A Universal Hilbert Space

York, M. J. (michael.york@physics.oxon.org)

July 10, 2016

Abstract

We propose a unifying quantum framework in which Einstein's equivalence principle is generalized to a universal Hilbert space in which all interaction is treated as a generalization of a frame transformation and represented by a change of basis. In our scheme intrinsic information is carried by a physical system independently of any frame of reference (or basis). A classical observer imposes a frame of reference in which that intrinsic information is expressed in terms of an observer-dependent basis (now including space-time information). This is in contrast to the usual description in which a frame transformation is treated as a unitary operation on a state vector in a restricted Hilbert space. At the level of non-interactive QM the two treatments are equivalent. It is when we consider interaction that the difference becomes clear.

A change of basis is not limited to the usual space-time transformations on a single particle. By employing a Hilbert space able to represent all possible physical states including composite states, we see that a change of basis from a two-particle basis to a single-particle basis is a structural transformation able to represent inelastic interaction. We show how the usual scattering operator is replaced by a generalized change of basis in our picture.

In a context in which all sources of observer information must be logically consistent, frame-independence of intrinsic information is also the source of apparent "non-locality" and incomplete information (for any and all observers) the only source of quantum uncertainty. Once complete information is available to any observer, it is, *in principle* available to all whether they are aware of it or not. We show how the standard proposed paradoxes of quantum mechanics are resolved.

1 Introduction

Ever since the proposal of the collapse of the wave-function as an explanation of the role of the observer in quantum mechanics(QM), a long history of both theoretical analysis [1][2] and experimental evidence [3][4][5][6][7][8] on the fundamental meaning of superposition has led to the alternative concepts of *non-locality* or *violation of counterfactual definiteness*. In the non-local picture, the collapse of the wave-function attributable to observation also triggers the remote and superluminal collapse of the wave-function of an entangled but unobserved system into a state determined by the observed system. If violation of counterfactual definiteness is taken as the resolution of the experimental evidence then time-dependent evolution is brought into question.

Throughout this history it has been typically assumed that the wave-function is a physical space-time-dependent property of real systems – which necessarily depends on the concept of space-time. Indeed, the very concepts of non-locality and counterfactual definiteness have meaning only in a space-time context. However, relativity theory has taught us that space-time requires an observer-dependent frame of reference. *So what then is space-time in the absence of observation?*

Work on the quantum gravity problem has led to the notion that space-time is an *emergent* property of quantum entanglement[9] rather than fundamental to reality. We take the view here that classical co-ordinate space-time is a creation of an observer, in order to describe interactive phenomena and relate diverse events. A physical system viewed by an observer as local to a space-time point or trajectory carries only the *intrinsic* information contained in its own state and that intrinsic information is independent of the observer. The intrinsic information itself can carry no space-time data since such data would vary from observer to observer. It is the observer that attaches their own frame-dependent description (including a space-time frame) to the intrinsic state information thereby specifying a basis set and, prior to actual observation, the superposition it implies.

A motivating factor in Einstein's development of general relativity was the notion that acceleration and gravity were equivalent[10]. Effectively, an observer in an accelerating frame of reference relative to an object sees that object as undergoing a force. But space-time transformations alone are not sufficient to describe all interaction. Instead, a key part of our proposal here is that all forces, all interaction in QM, is equivalent to a generalized "frame" transformation in a universal Hilbert space and represented by a change of basis. *Isolated interacting systems are described by a state with definite (conserved) intrinsic information; differing appearances of that state are described in terms of different basis sets chosen by observers.* Gravitational "action-at-a-distance" is then described by such a transformation in a way that is similar to any other form of elastic scattering.

Moreover, an observer is not merely a recipient of information from events; it can also, by a process of event selection or apparatus manufacture for example, be a *conditioner* of relevant information and the possibility of instigation and/or selection limiting the uncertainty is inherent in the quantum concept of an observer and the basis set that observer chooses. Any resulting probabilities of state measurements will then be conditional on the experimental set-up. The importance of this conditional aspect of the quantum probability distribution on the nature of the observation being made is often forgotten when theorists assume that uncertainty is somehow inherent in physical reality, since those conditions affect the distribution itself; but since those observational conditions can be arbitrarily deterministic[1], such conditional dependence would not be possible if the distribution were an intrinsic property of the system being observed rather than the observational context.

For example, once intrinsic information is available to a primary observer it can in principle be communicated to other observers. If a secondary observer also obtains information by direct observation – or any other source – then the logic on which all science is built requires that it be consistent with any information that could be communicated by the primary. The uncertainty of a secondary observer's information, prior to actual observation, is then limited only by any prior information that has indeed been previously communicated, but the fact that the system has already been observed and any future observation must give the same result, means that the state of the system will be definite (unless it has interacted in the meantime) and not uncertain. The secondary observer's knowledge of the state of a physical system can then always be resolved by *either* direct observation *or* by further communication from the primary observer. *But if both sources are available then they must be consistent.* This is a classical notion that, by simple logic, must apply to all observation including that of quantum systems[2]. Once information is available at any space-time location it is available at any other location that is separated by a time-like or light-like interval and, by scientific logic, cannot be contradicted by a subsequent measurement at the other location.

By sharing information multiple classical observers can build a space-time framework in which they can relate multiple events and their component systems according to empirical rules governing space-time behavior. This is how theories of space-time dynamics are built. But the underlying dynamics is one of Hilbert space and basis transformation.

2 Physical Systems And Observers

A major source of confusion in the historic development of QM has been the role of the observer, the notion of a space-time wave-function and the relationship between them. We see this confusion as having its origin in the notion that space-time co-ordinates are a property of a physical system rather than a property imposed by an observer.

In what follows we shall attempt to describe physical systems by the *intrinsic* information they carry with the proviso that this information is not dependent on any observer's space-time frame but can be passed from observer to observer unchanged. In the usual Hilbert space formulation, a given basis set is defined by a set of allowed quantum numbers and the information carried by a state is confined to a frame-dependent selection of a ray and can be expressed as an eigenvector or a superposition in that chosen basis. In that formulation, the ray that represents the state

[1] A particle produced in a definite intrinsic quantum state carries no uncertainty about its available information, for instance. It is only in any given observer-dependent basis that, because the state may be a superposition, observer-dependent information is incomplete. It is always possible to find a basis in which intrinsic information is an eigenstate.

[2] We can also view it the other way around as an additional imposition of the (scientific) observer.

changes as we transform from one space-time frame to another. In our formulation, the observer's choice of frame is instead a critical part of the observer-dependent basis set defining the physical state in terms of a given set of allowed quantum numbers, but in all frame transformations, the *intrinsic* state information itself and its state vector (uniquely selected from its ray) are preserved; only the frame-dependent basis set changes.

2.1 A Universal Hilbert Space

We shall define our Hilbert space $\mathcal{H}$ as a single universal space in which the intrinsic information I carried by any physical system is represented by a unique vector $|I>$ selected[3] from a given ray. Most importantly, that vector representing the intrinsic information is *independent of how we choose to express that information.* For instance, a reference frame defines a particular expression of that information, but the intrinsic information and its representational vector is independent of the choice of frame. Likewise, if the information comes in parts, the state vector representing the intrinsic information must be independent of the order in which we describe those parts.

Given a classical observer (CO) – or potential CO – of that information with a reference frame F, the observable states O form a complete set of basis vectors which we shall write as $|F(O)>$ and which must also be uniquely chosen. We can think of O as a frame-dependent expression of the information I.

For any CO and any F, there exists a basis, which we shall call the fundamental basis, in which the observables O are a list of quantum numbers, $E = (e, \mathbf{p}, s, \mu, \{q\})$, where e is energy, $\mathbf{p}$ is 3-momentum, s is spin, μ is the projection of spin along the quantization axis $\hat{\mathbf{z}}$ and $\{q\}$ represents additional quantum numbers presumably arising from some symmetry group. Typically this list of quantum numbers would define the state of a single particle. However, in our $\mathcal{H}$ they would specify the "total" quantum numbers of a single system, whether elementary or composite. These quantum numbers label the eigenstates of one possible basis set when associated with a frame F. It is tempting to think of these quantum numbers as independent variables; but, as seen by any observer, we expect that μ is restricted by the value of s and also that e and $|\mathbf{p}|$ are related[4]. So, for the moment, we shall leave open the possibility that there are inter-relationships that limit the available range of eigenstates. Composite states with multiple sets of E, each (optionally) with its own frame of reference, will also form possible basis sets.

2.1.1 Transforming Frames

Given information I, we can then write it as a superposition in the frame F as

$$|I> \quad = \quad \sum_O |F(O)><F(O)|I> \tag{1}$$

[3]Although possible selections can differ by a complex scalar factor, a unique selection must be made.

[4]Although we are not yet compelled to restrict ourselves to the Lorentzian case.

where the sum is over all members O of the basis set labeled by F (and perhaps an integral for continuous quantum numbers such as the intrinsic energy). We shall call the scalar $< F(O)|I >$ the *availability* of the state O in the frame F given the information I. The quantities $| < F(O)|I > |^2$ give the relative frequencies of observing the states O in F given the information I. From now on, we shall assume that $|I >$ and $|F(O) >$ are both appropriately normalized so that $| < F(O)|I > |^2$ gives the unique statistical probability. Likewise, in a different frame/basis F' we have

$$|I> \quad = \quad \sum_{O'} |F'(O')>< F'(O')|I> \tag{2}$$

so the frame transformation is equivalent to a change of basis. Note that any scalar multiplier[5] of $|I >$ that we might arbitrarily apply when changing frames can be absorbed as a common factor into the availabilities and this is what enables us to choose both a unique frame-independent vector $|I >$ and a unique basis set F from their rays. In particular if there is a frame F in which I is an eigenstate O then it can be expressed as a superposition in the the basis F' as

$$|F(O)> \quad = \quad \sum_{O'} |F'(O')>< F'(O')|F(O)> \tag{3}$$

This is in contrast to the normal QM scheme in which a frame transformation is described by a unitary operator $\hat{U}(\mathsf{T}(F, F'))$ representing the transformation T that takes $F \to F'$:

$$\begin{aligned} |F(O)> \quad &\to \quad \hat{U}(\mathsf{T}(F, F'))|F(O)> \\ &= \quad \sum_{O'} |F(O')>< F(O')|\hat{U}(\mathsf{T}(F, F'))|F(O)> \\ &= \quad \sum_{O'} |F(O')> U_{O'O}(\mathsf{T}(F, F')) \end{aligned} \tag{4}$$

(Conventionally, the explicit frame indications F is usually omitted from the state vectors which are usually labeled only by O. However, F is obviously implied since the states O demand a frame of reference to be meaningful.)

However, equivalence between 3 and 4 can be seen from the identification

$$\hat{U}(\mathsf{T}(F, F'))|F(O)> \quad = \quad |F'(O)> \tag{5}$$

$$< F'(O')|F(O)> \quad = \quad U_{O'O}(\mathsf{T}(F', F)) \tag{6}$$

and interchanging $F \leftrightarrow F'$ in 4. That is, in the traditional scheme the frame change is represented by the frame-dependent informational change $I \to I'$ in a fixed basis with a corresponding change in the vector that represents it; whereas in our scheme, the change in frame $F \to F'$ is

[5] Or phase factor only, if $|I >$ is properly normalized.

represented by a change of basis while explicitly preserving the frame-independent information content I and the vector that represents it and it is the availabilities of the observable states O that are changed,

$$\begin{aligned} < F(O)|I > \quad &\rightarrow \quad < F'(O)|I > \\ &= \sum_{O'} < F'(O)|F(O') >< F(O')|I > \\ &= \sum_{O'} U_{O,O'}(\mathsf{T}(F',F)) < F(O')|I > \end{aligned} \tag{7}$$

2.1.2 Quantum Equivalence Principle

The interpretation of $| < F'(O')|F(O) > |^2$ (from 6) as the relative frequency of finding a state O' in basis/frame F', given a state O in basis/frame F is the essence of our Quantum Equivalence Principle. It is the statement that quantum forces are indistinguishable from a generalized frame transformation given by a change of basis. The quantity $U_{O'O}(F',F)$ is the scattering amplitude for the transition $O \rightarrow O'$ and is equivalent to the availability of O' from O given the change in basis specified by $F \rightarrow F'$. In conventional QM, the notion of a frame transformation is normally concerned with space-time frames. So for a given observer, with a fixed space-time frame, there may appear to be no apparent frame transformation. What we have suggested here is that the concept of a frame transformation be generalized to a change of basis.

Suppose an observer sets up the apparatus to create an initial system in basis F then sets up the detection system to view the system in basis F'. The resulting scattering rate from state O to state O' is then given as the squared magnitude of the availability of O' in basis F' given O in basis F. We claim that, whether or not the observer specifically creates such basis choices, they are always available and equivalent to any observed "interaction". What a CO sees as *interaction* between two or more systems can then be interpreted as such a change of appearance or description and again described in $\mathcal{H}$ by a change of basis that preserves the intrinsic information unchanged.

Now we recall that we have insisted that $\mathcal{H}$ is *universal*, by which we mean that it is not merely limited to single states such as elementary particles, but also includes composite states with multiple components. Furthermore, basis transformations may now include changes to $\{q\}$ as well as energy/momentum/spin. But differing state descriptions will again be represented by the same vector if they carry the same intrinsic, frame-independent, information. The informational distinction we make between different composite systems represented by the same vector in $\mathcal{H}$ is purely, like energy-momentum-spin, a property of a given frame of reference not an intrinsic property of the state itself and we can think of such observer-dependent changes of informational description as a generalized frame transformation where "frame" clearly has a much wider meaning than the usual concept of a space-time frame but can still be represented by a change of basis.

For example, an eigenstate of a single system may also be a superposition of multi-component states. A particle decay would be an example of such an interactive transformation in which the transformation in observables is *structural*. In this case we can think of an interactive transformation as a change in the basis set from a single state basis to a composite basis. Likewise a multi-component system in which each component is separately observed in an eigenstate can be described by an interactive transformation as a superposition of single system eigenstates. Inelastic scattering can then be seen as an interactive transformation composed of not just distinct spatial transformations on individual particles, but also accompanied by linked identity transformations.

Elastic scattering of elementary particles would then be described by an interactive transformation composed of separate spatial transformations to each particle state whilst preserving the intrinsic information in the "before" and "after"[6] scattering. In elastic scattering of elementary particles there is, of course, no change in identities. But there is still the possibility of an equivalent transformation. In particular, we could describe such elastic scattering by a rotation of the center of momentum frame and possible rotations of the individual spin projection frames[7]. This gives us the angular distribution and spin distribution for a given energy. To determine the energy dependence we would have to know the energy dependence of the availabilities. Clearly this would imply the energy dependence of elastic scattering as the microscopic limit of the same "universal force" that includes gravity.

Employing the frame specification explicitly in identifying a basis is what enables the concept of frame-independent information. The corollary is that the basis states and availabilities then become the frame-dependent properties rather than the intrinsic informational state.

In general, 3 tells us that an eigenstate in one basis will transform to a superposition in another. For instance a rotation applied to the spin frame of a fundamental state will, in general transform an eigenstate of μ to a superposition of μ' eigenstates. However, a rotation about the quantization axis will result only in a change of phase and a 2π rotation will result in a possible sign change $< F(E)|F'(E) >= (-)^{2s}$. This shows explicitly the importance of including the frame specification – and in a way that explicitly accounts for odd rotations of 2π – in the basis eigenstate descriptions. And although this means the availabilities will change phase or sign, the relative frequencies and probabilities are, of course, unchanged.

For some transformations, then, the frame change $F \rightarrow F'$ results in the eigenstate transformation $O \rightarrow O'$ where O' is an eigenstate in the frame F'. Then both eigenstates are represented by an eigenvector on the same ray so that, when properly normalized, we have for a given pair O, O',

$$|< F'(O')|F(O) >| \quad = \quad 1 \tag{8}$$

[6] *Before* and *after* are obviously terms that have meaning only to an observer with a space-time frame.

[7] A spin frame is one in which we choose the **z**-axis to be that in which we measure the spin projection μ and need not necessarily coincide with the frame in which we measure $\mathbf{p}$. The full specification of a momentum-spin frame requires specifying both the momentum frame and the spin frame.

$$\text{or} \quad |U_{O'',O}(\mathsf{T}(F',F))| \;=\; \delta(O''-O') \tag{9}$$

So the frame change results, at most, in a phase change for the basis vectors. And if we again require that the information contained in $F(O)$ is identical to that contained in $F'(O')$ then we must choose our basis states such that[8]

$$\begin{aligned} |F(O)> \;&=\; |F'(O')> \qquad \text{and} \\ <F'(O')|F(O)> \;&=\; 1 \qquad \text{whenever } F \to F' \text{ implies } O \to O' \end{aligned} \tag{10}$$

Note that we can also define a transformation by its effect on the state O:

$$\hat{U}(\bar{\mathsf{T}}(O,O'))|F(O)> \;=\; |F(O')> \tag{11}$$

and 10 tells us that whenever the state O in frame F and the state O' in F' share the same intrinsic information, then the state transformation is the inverse of the frame transformation:

$$\bar{\mathsf{T}}(O,O') \;=\; \mathsf{T}(F,F')^{-1} \;=\; \mathsf{T}(F',F) \tag{12}$$

An example of such a transformation would be a Lorentz boost taking $E \to E_L$:

$$\begin{aligned} <F_L(E_L)|F(E)> \;&=\; U_{E_L,E}(\bar{\mathsf{T}}(E,E_L)) \;=\; U_{E_L,E}(\mathsf{T}(F_L,F)) \\ &\propto\; \delta(e_L - \sqrt{e^2 - p^2 + (p_L)^2}) \end{aligned} \tag{13}$$

(Any other factors would depend on how the other variables are transformed. For the spin projection this would depend on the choice of orientation of the spin frame.)

Regardless of what particular transformation we consider, the relationship 10 tells us that a basis vector can represent a (different) eigenstate in multiple different frames/bases. So, although a frame choice specifies a basis set and a frame transformation will in general imply a change of basis set, a basis vector does not imply a unique frame or basis. *To ensure a unique basis we must include the frame specification along with the eigenstates.*

2.1.3 The Intrinsic Frame

Now consider a system in a fundamental basis in frame F_0 where the momentum vanishes ($\mathbf{p} = \mathbf{0}$). The fundamental eigenstates E_0 are given by observables $m, \mathbf{0}, s, \mu, \{q\}$. For a single massive particle this would be the "rest" frame. Even for a massless particle, we can still choose the basis with quantum numbers $0, \mathbf{0}, s, \mu, \{q\}$ regardless of whether the frame for this basis is physically attainable. For a composite system we can choose the total quantum numbers in the center of momentum (CM) frame to designate the fundamental basis.

Furthermore there is a special frame – which we shall call the *intrinsic* frame – in which the spin quantization axis $\hat{\mathbf{z}}$ of the spin quantization frame is chosen so that we have a spin eigenstate with $\mu = j$. Then we

[8]Note that the transformation $O \to O'$ is the *inverse* of $\mathsf{T}(F,F')$.

can write the intrinsic eigenvector by dropping the redundant $\mathbf{p} = \mathbf{0}$ and $\mu = j$ variables and using a rounded ket, $|..)$, as

$$|\tilde{E}) \;=\; |m, s, \{q\}) \quad = \quad |\tilde{F}(\tilde{E}_0) > \;=\; |\tilde{F}(m, \mathbf{0}, s, s, \{q\}) > \tag{14}$$

where $\tilde{F}$ is the intrinsic frame.

This intrinsic state carries no space-time dependent state observables (such as those which specify the direction of motion or angular momentum orientation) at all. Space-time dependence is introduced by the observer by transforming the intrinsic frame to their own frame. The energy-momentum information in a general space-time frame[9] F is then specified entirely by the observer's choice of rotations and boosts that take it from the intrinsic frame. In particular we can represent the intrinsic information expressed in an arbitrary fundamental frame/basis F by

$$\begin{aligned} |\tilde{E}) &= \hat{U}(\mathsf{T}(F, \tilde{F}))|F(\tilde{E}_0) > \\ &= \sum_O |F(O) > U_{O,\tilde{E}_0}(\mathsf{T}(F, \tilde{F})) \end{aligned} \tag{15}$$

and thus the availability of an eigenstate O in a frame F, given an intrinsic state $\tilde{E}$ is

$$< F(O)|\tilde{E}) \quad = \quad U_{O,\tilde{E}_0}(\mathsf{T}(F, \tilde{F})) \tag{16}$$

As an example of a pure space-time transformation from the intrinsic state, we can use the prescription of Wigner[11] of rotating the intrinsic frame into one in which we choose the projection axis to be the direction of the boost, then applying the boost followed by a rotation to assign the desired direction of motion:

$$\hat{U}(\mathsf{W}(\mathbf{p})) \quad = \quad \hat{U}(\mathsf{R}(\hat{\mathbf{p}}))\hat{U}(\mathsf{B}(p))\hat{U}(\mathsf{R}_I^{-1}) \tag{17}$$

where R_I is a rotation which takes the boost direction into the intrinsic projection axis where $\mu = j$, $\mathsf{B}(p)$ is the boost which generates the momentum $p = |\mathbf{p}|$ in the direction $\hat{\mathbf{z}}$ and $\mathsf{R}(\hat{\mathbf{p}})$ takes the momentum into the intended direction $\hat{\mathbf{p}}$. It is in this way that, using a space-time transformation $\mathsf{W}(\mathbf{p})$, we introduce the space-time interpretation of energy, momentum and spin angular momentum. From 10 and 12 we see that if E is the eigenstate that results from applying $\bar{\mathsf{T}}(\tilde{E}, E) = \mathsf{W}(\mathbf{p}) = \mathsf{T}(F, \tilde{F})$ to the intrinsic state $\tilde{E}$, then

$$|F(E) > \quad = \quad |\tilde{E}) \;=\; \hat{U}(\mathsf{W}(\mathbf{p}))|F(\tilde{E}_0) > . \tag{18}$$

Note also that the prescription 17 can be used for any kind of momentum boost and is not confined to a Lorentz boost.

[9] We shall use the terms "space-time frame/transformation/dependence" loosely to include frames/transformations/dependence in energy-momentum-spin space. Most of the space-time transformations we shall discuss will be energy-momentum-spin transformations such as rotations and boosts (translations in energy-momentum space). Bear in mind, also, that the frame transformation from energy-momentum space to co-ordinate space-time is itself well-known to be merely a change of basis.

2.1.4 The Vacuum State

We think of the vacuum as containing no information. Let us represent the vacuum state in its intrinsic frame by the fundamental state vector $|0) = |F_0(0, \mathbf{0}, 0, 0, \{0\}) >$. Since this state is represented by a vector in the universal Hilbert space, we can write it as a superposition in any basis F as

$$|0) \quad = \quad \sum_O |F(O) >< F(O)|0) \tag{19}$$

That is, the vacuum, like any other state can acquire quantum numbers that are frame dependent with availabilities determined by the transformation that takes its intrinsic frame to an observer's frame F. Naturally, we expect $< F(O)|0)$ to vanish for all O that don't have net vacuum quantum numbers. Thus, apart from the trivial state $\tilde{E} = (0, 0, \{0\})$, any other states will have at least two components and such two-particle states, for instance, will necessarily be particle-antiparticle states.

Furthermore, since $|0)$ is a vector in $\mathcal{H}$ [10], there is a unitary transformation that will take it into any other state vector.

Taking our quantum equivalence principle to its logical conclusion we can imagine there being a frame of reference that any observer could transform to, in which the universe, taken as a single whole system, has the trivial informational properties of the vacuum[11]. But in any other frame, the change of basis is sufficient to give the universe the properties seen by an observer. All it takes for such an observer to see a non-trivial universe is that they specify a frame of reference with its associated basis. Likewise, all it takes for such an observer to exist is that there be frame transformations in which the properties of an observer materialize.

2.2 Two-Component States

Consider two states carrying information I_a, I_b. Why should the observable information come to us in this form? One situation might be where the two parts come from different COs possibly describing their distinct partial information in different frames/bases.

Suppose the two vectors $|I_a >$ and $|I_b >$ lie in distinct subspaces $\mathcal{H}_a$, $\mathcal{H}_b$ of $\mathcal{H}$. Conventionally, we represent the two-component composite state by the vector

$$|I_a; I_b\} \quad = \quad |I_a > |I_b > \tag{20}$$

in the direct product Hilbert space $\mathcal{H}_a \otimes \mathcal{H}_b$ and we have used the braced ket $|..\}$ to indicate the order-dependent product vector.

Now, since each of the states I_a, I_b can be represented as a superposition in any given basis, we find that $|I_a; I_b\}$ can also be represented as a superposition in a bi-fundamental basis in $\mathcal{H}_a \otimes \mathcal{H}_b$:

$$|I_a; I_b\} \quad = \quad \sum_{E_a, E_b} |F_a(E_a); F_b(E_b)\}\{F_a(E_a); F_b(E_b)|I_a; I_b\} \tag{21}$$

$$\tag{22}$$

[10] Actually a fundamental eigenstate.

[11] That is *nothing*.

where

$$\text{where} \quad |F_a(E_a); F_b(E_b)\} \quad = \quad |F_a(E_a) > |F_b(E_b) > \tag{23}$$

However, the ordering in 20, 21 and 23 is an artifice of our construction of the direct product space. We could equally well represent the the two-component state by

$$|I_b; I_a\} \quad = \quad |I_b > |I_a > \tag{24}$$

in the direct product Hilbert space $\mathcal{H}_b \otimes \mathcal{H}_a$ with bi-fundamental basis $|F_b(E_b); F_a(E_a)\}$. Either case should give the same relative frequencies and so, if properly normalized, we must have that

$$|\{F_a(E_a); F_b(E_b)|I_a; I_b\}| \quad = \quad |\{F_b(E_b); F_a(E_a)|I_b; I_a\}| \tag{25}$$

2.2.1 Order Independence

But we have demanded that the intrinsic information in a physical system be represented by a unique vector in $\mathcal{H}$ – regardless of how many fundamental components it has. In particular any ordering we introduce in listing that information is irrelevant. The net intrinsic information, which we can write symbolically as $I = I_a + I_b$, is then independent of the order in which we describe its separate components since the ordering is part of the basis choice just like any other choice of basis. Therefore, using our basis-independent prescription it must be represented in $\mathcal{H}$ by a unique vector $|I >$ which must be both observer-independent and order-independent.

We can write $|I >$ in terms of a bi-fundamental basis in either ordering:

$$\begin{aligned} |I > \quad &= \sum_{E_a, E_b} |F_a(E_a); F_b(E_b) >< F_a(E_a); F_b(E_b)|I > \\ &= \sum_{E_a, E_b} |F_b(E_b); F_a(E_a) >< F_b(E_b); F_a(E_a)|I > \end{aligned} \tag{26}$$

where, again, uniqueness requires that the basis vectors must also be order-independent:

$$|F_a(E_a); F_b(E_b) > \quad = \quad |F_b(E_b); F_a(E_a) > \tag{27}$$

$$< F_a(E_a); F_b(E_b)|I > \quad = \quad < F_b(E_b); F_a(E_a)|I > \tag{28}$$

Equivalence with 21 then requires that the availabilities should give the same relative frequencies. Order-independence in $\mathcal{H}$ then requires

$$\begin{aligned} < F_a(E_a); F_b(E_b)|I > \quad = \quad & \alpha[\{F_a(E_a); F_b(E_b)|I_a; I_b\} \\ & + \{F_b(E_b); F_a(E_a)|I_b; I_a\}] \end{aligned} \tag{29}$$

where α is a normalizing scalar factor.

Instead of observing a two-component state in two separate frames of reference F_a and F_b we would normally consider a basis specified by a single common frame of reference F for both states, so that

$$\begin{aligned}|I> &= \sum_{E'_a,E'_b} |F(E'_a;E'_b)><F(E'_a;E'_b)|I> \\ &= \sum_{E_a,E_b,E'_a,E'_b} |F(E'_a;E'_b)><F(E'_a;E'_b)|F_a(E_a);F_b(E_b)> \\ &\quad <F_a(E_a);F_b(E_b)|I> \end{aligned} \tag{30}$$

so we must now consider the availability $<F(E'_a;E'_b)|F_a(E_a);F_b(E_b)>$ of the eigenstate $E'_a;E'_b$ in common frame F, given the eigenstates E_a, E_b in frames F_a, F_b, respectively.

Since a CM frame F_{CM} is a simple example of a common frame, we first seek a means to relate the two independent bases F_a, F_b to F_{CM}. In this frame we must have $\mathbf{p}'_a = \mathbf{p} = -\mathbf{p}'_b$. We can treat this as a rest frame of the bi-fundamental system. Any other common frame can be obtained by transforming from F_{CM}.

We recall from 18 that the bases F_a and F_b are defined by the transformations $\mathsf{F_a}$ and $\mathsf{F_b}$. It is easy to see that if we employ 17 to specify both bases by the same transformation $\mathsf{F_a} = \mathsf{F_b} = \mathsf{W}(\mathbf{p})$ we apparently obtain a common basis F with $\mathbf{p}_a = \mathbf{p}_b = \mathbf{p}$ but this cannot be a CM frame unless $\mathbf{p} = \mathbf{0}$. Since any other physically accessible common frame should be accessible by transforming from a CM frame[12], this tells us that we cannot obtain any non-trivial common frame by applying the same basis transformation to the separate intrinsic states. In other words, choosing the same transformation F for both states according to 15 will not, except in a trivial case such as $\mathsf{F} = \mathsf{W}(\mathbf{0})$, give us a common frame for both states.

Rather, following York[12], let us consider the case where the final z-axis for both F_a and F_b is given by the vector $\mathbf{k}$ which bisects the angle 2θ between $\hat{\mathbf{p}}_a$ and $\hat{\mathbf{p}}_b$. Then we can choose the final rotation $\mathsf{R}(\hat{\mathbf{p}}) = \mathsf{R}(\mathbf{z} \rightarrow \hat{\mathbf{k}})$ to be the same rotation by θ about the y-axis (chosen to be perpendicular to the plane of $\hat{\mathbf{p}}_a$ and $\hat{\mathbf{p}}_b$) for both states. However these rotations necessarily require opposite x, y-axes. For example, if we choose $\mathbf{y}_a = \hat{\mathbf{p}}_a \times \hat{\mathbf{p}}_b$ then we must also choose $\mathbf{y}_b = \hat{\mathbf{p}}_b \times \hat{\mathbf{p}}_a = -\mathbf{y}_a$ in order that the angle of rotation is θ in both cases.

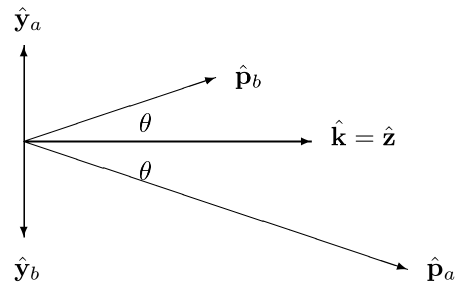
Thus to obtain a common frame, we must then rotate about $\mathbf{k}$ to take $\mathbf{y}_b \rightarrow \mathbf{y}_a$ (or *vice versa*). That is, to transform $E_b \rightarrow E'_b$ in a common energy-momentum frame F_a, for example, we must employ a rotation for $\mathbf{p}_b \rightarrow \mathbf{p}'_b$:

$$\hat{U}(\mathsf{W_a}(\mathbf{p}'_b)) = \hat{U}(\mathsf{R}_\mathbf{k}(\pm\pi))\hat{U}(\mathsf{W_b}(\mathbf{p}_b)) \tag{31}$$

and $\mathsf{R}_\mathbf{k}(\pm\pi)$ is a rotation by either $+\pi$ or $-\pi$ about $\mathbf{k}$ and $\mathbf{p}'_b$ is the momentum of b in frame F_a. As long as we make a consistent choice of $\mathbf{k}$ and the direction of rotation by π then 31 will uniquely specify the relation between F_a and F_b. Defining

$$|F(E_a;E_b)> = |F(E_a);F(E_b)> \tag{32}$$

[12] For example, this must be so if the bi-fundamental state is expressible as a superposition of single fundamental states that can be transformed to an intrinsic frame.



and employing 6 and 27 and choosing F to coincide with F_a we see that 31 allows us to write

$$\begin{aligned} < F_a(E_a; E_b')|F_a(E_a); F_b(E_b) > &= < F_a(E_b')|F_b(E_b) > \\ &= U_{E_b{}',E_b}(\mathsf{R}_{\mathbf{k}}(n_b\pi)) \end{aligned} \tag{33}$$

where $n_b = \pm 1$ and we have

$$U_{E_b{}',E_b}(\mathsf{R}_{\mathbf{k}}(n_b\pi)) = (-1)^{n_b\mu_b}\delta(e_b' - e_b)\delta(p_b' - p_b)\delta(\hat{\mathbf{p}}_b' - \bar{\mathbf{p}}_b)\delta_{\{q_b'\},\{q_b\}} \tag{34}$$

and $\bar{\mathbf{p}}_b$ is obtained from $\hat{p}_b$ by the rotation. We notice the sign ambiguity in n_b leaves a sign ambiguity in $U_{E_b{}',E_b}(F_a, F_b)$ for fundamental systems with half-integer s_b. Clearly, the unique specification of $|F_a(E_a; E_b') >$ for such states then requires the unique specification of n_b. In any other frame F,

$$\begin{aligned} < F(E_a'; E_b')|F_a(E_a); F_b(E_b) > = \; & U_{E_a',E_a}(\mathsf{T}(F, F_a)) \\ & \sum_{E_b''} U_{E_b',E_b''}(\mathsf{T}(F, F_a))U_{E_b'',E_b}(\mathsf{R}_{\mathbf{k}}(n_b\pi)) \end{aligned} \tag{35}$$

and, by the same reasoning, we have the alternative expression

$$\begin{aligned} < F(E_b'; E_a')|F_b(E_b); F_a(E_a) > = \; & U_{E_b',E_b}(\mathsf{T}(F, F_b)) \\ & \sum_{E_a''} U_{E_a',E_a''}(\mathsf{T}(F, F_b))U_{E_a'',E_a}(\mathsf{R}_{\mathbf{k}}(n_a\pi)) \end{aligned} \tag{36}$$

and we see that – depending on how we choose n_a and n_b – there is the possibility of introducing an order-dependence in establishing the common frame state vector for states in which one or more of the fundamental states has half-integer spin. In order to regain order-independence and satisfy 32 and 27, so that

$$|F(E_b; E_a) > \equiv |F(E_a; E_b) > \tag{37}$$

we must demand the relationship

$$\hat{U}(\mathsf{R}_{\mathbf{k}}(n_b\pi)) = \hat{U}(\mathsf{R}_{\mathbf{k}}(n_a\pi)^{-1}) \tag{38}$$

$$\text{or} \quad n_a = -n_b \tag{39}$$

2.2.2 The Spin-Statistics Theorem

The symmetrization under re-ordering we have demanded in 26 and **??** may appear, at first sight, to fly in the face of the conventional expression of the spin-statistics theorem as anti-symmetrization of states of identical particles with half-integer spin. However, it should be noted that the familiar anti-symmetrized states are normally expressed assuming an implied common frame $F_a = F_b = F$ and this requires us to recognize the geometric asymmetry as expressed in 35 and 36. It is easily seen then that, any possible order dependence in defining $< F(E'_a; E'_b)|F_a(E_a); F_b(E_b) >$ depends on how we choose the signs n_a and n_b.

The effects of these choices are discussed in fuller detail in [12]. In particular, our principle of invariance of intrinsic information leads to the spin-statistics theorem *when properly expressed in terms of observables*, rather than the misleading "symmetrization postulate". It was shown that the choice $n_a = n_b = n$ results in the usual pair-wise anti-symmetrization for half-integer spin but violates the consistency rule of a unique state vector satisfying 37 for given intrinsic information that we demand for our $\mathcal{H}$, whereas a consistent relationship between individual states, so that 38 holds, satisfies our order-independence requirement[13].

2.2.3 Interaction

Since bi-fundamental states are represented by vectors in $\mathcal{H}$, they can be expressed as a superposition in a mono-fundamental basis:

$$|F(E_a; E_b) > \quad = \quad \sum_E |\bar{F}(E) >< \bar{F}(E)|F(E_a; E_b) > \tag{40}$$

The meaning of the availability here is then that $| < \bar{F}(E)|F(E_a; E_b) > |^2$ gives the relative frequency of the pair of fundamental eigenstates E_a and E_b, in the observer's bi-fundamental frame/basis F, being collectively observable as a mono-fundamental eigenstate E in the observer's mono-fundamental frame/basis $\bar{F}$. If $\hat{U}(\mathsf{T}_{12}(F, \bar{F}))$ takes the mono-fundamental common basis F into a bi-fundamental basis $\bar{F}$, then we see that we have defined the scattering operator for the transition of the bi-fundamental state to the mono-fundamental state as:

$$\hat{S}_{21} \quad = \quad \hat{U}(\mathsf{T}_{12}(F, \bar{F})) \qquad \text{so that} \tag{41}$$

$$< F(E)|\hat{S}_{21}|F(E_a; E_b) > \quad = \quad < \bar{F}(E)|F(E_a; E_b) > \tag{42}$$

(from the equivalency that T_{12} takes a bi-fundamental state E_a,E_b into a single fundamental state E). Likewise, if we write a fundamental state as a bi-fundamental superposition:

$$|\bar{F}(E) > \quad = \quad \sum_{E_a, E_b} |F(E_a; E_b) >< F(E_a; E_b)|\bar{F}(E) > \tag{43}$$

[13]Note the corollary that supersymmetry is not permitted, since it would violate the order independence of our essential assumption of invariant intrinsic information unless we require that states of parallel momentum (and no CM frame) are permitted for identical supersymmetric partners.

then $| < (F(E_a; E_b)|\bar{F}(E) > |^2$ is the relative frequency of a mono-fundamental state being observable as a bi-fundamental state – in other words it is the relative decay rate of $E \rightarrow E_a + E_b$ in the frame F and again we have

$$\begin{aligned} < F(E_a; E_b)|\hat{S}_{12}|F(E) > &= < F(E_a); F_b(E_b)|\bar{F}(E) > \\ &= < \bar{F}(E)|F(E_a; E_b) >^* \\ \hat{S}_{12} &= \hat{S}_{21}^\dagger \;=\; \hat{U}(\mathsf{T}_{21}) \;= \hat{U}(\mathsf{T}_{12}^{-1}) \end{aligned} \quad (44)$$

By extension,

$$\begin{aligned} &< F_{cd}(E_c; E_d)|F_{ab}(E_a; E_b) > = \\ &\qquad \textstyle\sum_E < F_{cd}(E_c; E_d)|\bar{F}(E) >< \bar{F}(E)|F_{ab}(E_a; E_b) > \end{aligned} \quad (45)$$

is the scattering amplitude for $F_{ab}(E_a; E_b) \rightarrow F_{cd}(E_c; E_d)$ when properly normalized. We use the frame subscript to emphasize that the frame transformation we are describing is one in which the particle identities are transformed. We can write the scattering amplitude in the CO's frame F_{ab} employing a scattering operator:

$$< F_{ab}(E_c; E_d)|\hat{S}_{22}|F_{ab}(E_a; E_b) > = < F_{cd}(E_c; E_d)|F_{ab}(E_a; E_b) > \quad (46)$$

where the $2 \rightarrow 2$ scattering operator now becomes

$$\hat{S}_{22} \quad = \quad \hat{U}(\mathsf{T}_{22}(F_{cd}, F_{ab})) \quad (47)$$

and is the interactive "frame" transformation equivalent to the state transformation $E_a + E_b \rightarrow E_c + E_d$ and is clearly related to the intrinsic transformation $\tilde{E}_a + \tilde{E}_b \rightarrow \tilde{E}_c + \tilde{E}_d$ accompanied by any associated space-time transformations to the energy/momentum/spin projections for each individual fundamental state that are required in creating common frames F_{ab} and F_{cd}.

We see from 45 that scattering amplitudes can be computed from the $2 \rightarrow 1$ symmetrized vector couplings and these, in turn can be computed from the sum of the direct product (ordered) vector couplings. In general, any interaction $n \rightarrow m$ can be computed in this way. The key to the dynamics of such quantum systems is then to determine the ordered vector couplings.

We might imagine, in principle, the case where for each i, the $\{q_i\}$ are all vacuum numbers, then we should not expect them to show any effect on the scattering amplitude and dependency on the energies would then indicate in principle that this elastic scattering was purely gravitational in nature. Then 45 suggests that gravitation is not so much a distinct force but is integral to all interaction, its effect being weak except when energy contributes more significantly to availabilities than "charges".

3 Non-Physicality Of The Wave-Function

The picture we have outlined enables us to resolve many of the logical and philosophical problems that have bedevilled QM ever since the notion of a collapsing wave-function was first proposed. Wave-functions are mathematical forms that are posited to have a physical existence but collapse into a delta-function on measurement. This has led to a variety of problems concerning the role of the observer that are typically embodied in the concepts of either non-locality or violation of counterfactual definiteness, but, again we should point out, this only applies to space-time observers as only such observers have a space-time context. In our picture, reality is separated from a space-time context and embodied in intrinsic frame-independent information and the uncertainty implicit in the wave-function exists only because of the observer's lack of information; not because of any supposed uncertainty in physical reality.

Bell's theorem and the experimental observation of non-local entanglement is one of many examples of where the quantum debate is carried out. Two common others are the double-slit experiment and the Schrödinger's cat thought experiment. We shall explain all three of these in our picture of reality and its observers with the key explanatory factor that the intrinsic state of a system is definite and it is the observer's selection of a frame of reference (basis) in which to detect the state that is seen by the observer as triggering the "collapse of the wave-function" into a frame-dependent description. But since this frame selection takes place when the apparatus is set up, then the "collapse" takes place on set-up which, in general, will be well before the eventual state detection even though the result of this "collapse" may be unknown to any observer. There is no sense in which the actual system state, as opposed to any observer's knowledge of that state, is uncertain.

3.1 Non-local Entanglement

To illustrate this phenomenon in as simple a way as we can, let us consider a simple exposition of the experiment envisioned by Bell and experimentally tested on microscopic quantum systems. However, we shall do so by first describing a simple and familiar classical analogy.

A person takes a pair of gloves and puts each in a separate box and sends them off to opposite sides of the world. Someone opens the boxes as they are received. The sender knows which glove they put into each box, so which glove is in which box is communicable information. One receiver sees a right glove and, if they also know the *partial* information of a pair having been sent, will instantly know that someone else has been sent a left glove without there having to be any superluminal communication across the world. But, even if they didn't know about the initial pair, that partial information could be conveyed to them later. Likewise the complete information concerning which glove was placed in their box could be later communicated by the sender. Clearly any later information received from the sender cannot change the fact that they received the right glove and, if nature is logical (and non-deceitful), must confirm that it was a right glove that was put in the box they received.

Now let us consider the quantum entanglement case using entangled microscopic particles to substitute for gloves and ask what else is different. In the picture we have described here, the only significant difference is that there was no independent observer capable of knowing which particle was sent where when the quantum particles were emitted *because the experiment was set up that way.* The only information available was that an entangled pair was emitted. So there was no knowledge available to communicate to the recipient of the "right" particle that they should have indeed received a "right" particle, whether before or after they received it. The only information potentially available that could be later confirmed was the partial information that a pair of entangled particles was emitted (and would be later detected in the state it was despatched) and that information is incomplete because it entails uncertainty as to which particle was sent where. This uncertainty implies a superposition as seen by the potential observer even though the particle state is definite[14] because it is unknown to every other physical system except the particle itself. An alternative way of looking at this, perhaps easier to understand, is that the observer already knows which, *if any*, state will be detected because it is specified by the nature of the detector[15] and particles not in that state will simply not be detected. The uncertainty, in effect, then lies not with the observer, but with the ability of the observer's apparatus to detect the state.

In both cases, the glove/particle was always "right" and in both cases the recipient did not know that until they received it (or could only receive "right" particles). But, in the classical case, there was corroborative information available from the sender (whether transmitted or not) to confirm that they had sent a right glove whereas, in the quantum case, there was no information available from any source other than direct observation by a recipient to confirm that the particle had been emitted in a "right" state. Hence, in the quantum case, there was never any available information concerning which recipient was to receive which particle until one recipient detected a particle. But if the state had been observed at production, then a potential future observer would still assume a superposition unless and until they were informed otherwise. Indeed one can always imagine a secret observer at production who had already "collapsed" the wave-function but kept that information to themselves. Thus we can always treat the system as though the "collapse" had taken place immediately and it was just a matter of the future observer confirming the collapsed state. In this way we can divorce the "collapse" from actual observation and eliminate the problem of supposed superluminal communication.

Only the composite state that entangled the particles was knowable to the future observer unless and until a unique state is detected and this is why the particles, prior to observation, can only be described by such an observer as superpositions *no matter how definite their potentially observable eigenstates.* Nevertheless, it is necessary for only one recipient to observe their particle in order that the state of the other is known and communicable and therefore uniquely indicates the state of the other whether or not it is separately and directly observed and without any superluminal communication. Clearly, just as with the gloves, any such

[14]But the particle itself is the only entity which carries the intrinsic information specifying its precise state.

[15]Of course, multiple detectors can specify multiple detectable states but, ultimately, to determine a unique state requires unique detection.

direct observation of the other particle must give that unique result even if the other observer doesn't know what that state is – and therefore continues to represent it as a superposition – until it is directly observed or communicated. The violation of counterfactual definiteness and "collapse of the wave-function" are constructions of the space-time apparatus not properties of the entangled particles.

Likewise, it should be obvious from this example that, if quantum events take place in states that encapsulate all intrinsic information and that encapsulated information is frame-independent as we have suggested, then we can always assign a rest, even an intrinsic, frame to describe that state. So even in the classical space-time picture all interaction can be seen as local and intrinsic and the non-locality of continued entanglement does not in any way imply non-local interaction; it merely says that the entangled states seem spatially separate when observed in a common space-time frame as separate components of the encapsulating informational state.

3.2 Double Slits

We consider an idealized double-slit experiment with infinitely narrow slits. Contrary to the conventional viewpoint in which the space-time wave-function is considered to be a physical property of the particles, we claim that particles (that in principle could be seen by an observer to pass through a given slit) are produced in definite intrinsic states which specify which slit the particle will pass *because the experimental set-up requires that the particle pass through one slit or the other.* Those which do not pass through a slit do not reach the screen. If there were only one slit then a screen observer would also know the slit state of the produced particle.

In the case of two or more sufficiently narrow slits, each particle produced is selected to pass through a single slit and is therefore in a single slit eigenstate. The imposition of the double slit apparatus therefore selects the available intrinsic states independently of a future observer knowing which particle was selected to pass through which slit and particles which do not exist in a single slit eigenstate are deselected by the experimental setup which demands that a slit basis be used. However these intrinsic states possess no space-time information (other than that implicit in the slit location). The screen observer knows only that the particles it will detect exist in slit superpositions and it interprets these superpositions as a wave-function consisting of a sum of space-time delta-functions defining the two possible trajectories.

Now consider the case that the slits have finite width. Simply identifying the slit is not sufficient to specify the state of a produced particle. However, we can still divide the Hilbert space into two parts, one part representing the available states for each slit. The observer now interprets the slit superposition as a wave-function that is a sum of two wave packets smeared out according to the width of the slits.

Once again, it is the experimental setup that selects particles to pass through a given slit; but which slit is not ever determinable by the observer unless they observe each particle separately *at the slit.* Without doing so, their information will always be that of the slit superposition and seen at the screen as the interference of two wave packets. The interference pattern is then simply the probability distribution determined by the probabilities of the particle *being emitted* in a state that enables it to pass through either of the slits and being scattered from the slit in a determinate fashion according to its trajectory. Once again we see that the "collapse of the wave-function" really takes place at emission not at detection and is determined by the availabilities of the possible trajectories (when projected into the space-time frame of the apparatus) *given the emission system*.

3.3 Schrödinger's Cat

Schrödinger's cat is conventionally claimed to be in an indeterminate physical state neither definitely alive nor definitely dead, but in a superposition of alive and dead computable as a time-dependent wave-function. What this superposition means physically before the box is opened is never explained. Only the probability of the cat being found alive or dead when the box is opened is explained and, indeed, that is the key property for an observer outside the box before it is opened.

But an observer inside the box, immune to the poison, could see at any time whether the poison was released and the cat was alive or dead. In our picture, however, because the box is closed, such an internal observer sees only the space-time environment inside the box – including the cat and the poison – and cannot communicate with any external observer. Both observers see that a cat is put into the box alive and both know the state of the cat when the box is opened. The information available to the external observer is a superposition of alive and dead states (with relative availabilities being dependent on the time), but the internal observer, able to see whether the cat remains alive until either the box is opened or the poison is released and the cat is killed whereupon it remains in a dead state until the box is opened, knows the state of the cat as an eigenstate, either alive or dead, at all times.

But when the box is opened, the external observer must agree with the internal observer on the state of the cat. Furthermore, if the external observer waited long enough to be reasonably sure the cat was dead, any internal observer could then inform the external observer (with a synchronized clock) of the precise time at which the cat expired.

Since the experience of the external observer does not depend in any way on the presence or absence of an internal observer[16], we can conclude that the cat is always in a definite state, but an external observer does not know that state until they open the box. Once again we see that the violation of counterfactual definiteness implicit in Schrödinger's thought experiment is a property of the observer's ignorance only and not a property of the cat.

[16] In fact the cat itself could be described as an internal observer that communicates its state when the box is opened and might even communicate the time of its expiration to a skilled pathologist.

4 Classical And Quantum Probability

Classical probability is always associated with frequency counting. Theoretically it is *defined* to be the appropriately normalized mathematical encoding that exactly equals the relative frequency to which an infinite number of samples will converge. However, any other mathematical encoding that enables the unique computation of such a theoretical quantity also serves as a probability encoding of the asymptotic frequency ratio.

The utility of the superposition in describing the uncertainty concerning unavailable information comes from the Hilbert space description of physical states. Its utility in computing the probability encoding of the statistical observer counting frequencies is purely a convenient translation for the frequency counter.

However, the interpretation of the availability $< F(O)|I >$ as the "probability amplitude" of the observer's superposition with information I to be observed in the state O in frame F, as a means to compute a relative statistical frequency is not merely a mathematical trick but a genuine statement of a probability encoding at the real physical level of individual systems being observed in a specific eigenstate. It is a reflection of the probability of a particular state given the available information. An example would be the decay of a physical system in a definite fundamental state to component systems also in fundamental states. The individual amplitudes of the possible resulting states expressed as a composite superposition are real physical descriptions of the availability of a transitional state and if it were not for the unfortunate fact that the term "probability" has been ineluctably associated with frequency counting we could call them *quantum probabilities*. In deference to this unfortunate tradition we have instead called them *availabilities*.

Our purpose here is not to obscure the distinction between statistical probability and informational availability with a mere philosophical argument but to emphasize that the informational availability is just as valid a concept of probability as statistical frequency and *one that is more appropriate to the description of quantum-level interaction*. In fact, informational availability is physically more meaningful than statistical frequency because it is able to exactly describe a single quantum system *at a level prior to observation*, whereas statistical frequency requires a large number of observed samples to even be meaningful as an approximation.

5 Summary

We have proposed that physical states encapsulate frame-independent intrinsic information that is expressed in terms of observable properties by an observer that chooses a specific frame of reference. We have argued that all such states can be represented by a universal Hilbert space in which the choice of frame specifies a basis set and that a frame transformation is equivalent to a change of basis. We have shown how the interaction of systems that appear to an observer to be separate can be expressed in terms of a change of basis within that Hilbert space. In this way we have opened up quantum scattering theory to a means of accommodating gravity. By distinguishing between production in a definite state and the state information available to an observer, we have utilized this model to resolve the common "paradoxes" of quantum mechanics.

References

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

[2] Bell J. S., see "Speakable and Unspeakable in Quantum Mechanics," Cambridge University Press (1987) for a collection of Bell's papers on this subject.

[3] Clauser J. F., Horne M. A., "Proposed experiment to test local hidden variable theories", *Phys. Rev. Lett.*, **23** (15), 880-4.

[4] Clauser J. F., Horne M. A., "Experimental consequences of objective local theories", *Phys. Rev. D*, **10** (2), 526-35.

[5] Freedman S. J., Clauser J. F., "Experimental test of local hidden variable theories", *Phys. Rev. Lett.*, **28** (938), 526-35.

[6] Aspect A., Grangier P., Roger G., "Experimental Tests of Realistic Local Theories via Bell's Theorem" *Phys. Rev. Lett.* **47** (7) 460-3.

[7] Aspect A., Grangier P., Roger G., "Experimental Tests of Realistic Local Theories via Bell's Theorem" *Phys. Rev. Lett.* **49** (2) 91-4.

[8] Aspect A., Dalibard J., Roger G., "Experimental Test of Bell's Inequalities Using Time-varying Analyzers" *Phys. Rev. Lett.* **49** (25) 1804-7.

[9] See, for example, van Raamsdonk M., "Building Up Space-Time With Quantum Entanglement" *Int. J. of Mod. Phys. D* **19** (14) 2429-2435 (2010).

[10] Einstein A., "On the relativity principle and the conclusions drawn from it" *The collected papers of Albert Einstein. Vol. 2 : The Swiss years: writings, 1900-1909* (Princeton University Press, Princeton, New Jersey, 1989).

[11] Wigner, E. P., "Relativistic Invariance and Quantum Phenomena," *Rev. Mod. Phys.* **29**, 255-268 (1957).

[12] York, M. J., "Symmetrizing The Symmetrization Postulate", AIP Proceedings 545 (2000) "Spin Statistics Connection And Commutation Relations", ed. Hilborn and Tino, pp 104-110.