Bell's Future Quantum Mechanics - a Novel Interpretation

Douglas B. Sweetser

sweetser@alum.mit.edu

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This essay provides an introduction to a new interpretation for quantum mechanics. Here is the idea in two sentences:

> **Bell's** inequality, backed by experimental evidence[2, 1], shows that quantum mechanics must be non-local, thus the wave function is space-like separated from the observer at the origin, here-now. The product of the wave function and its conjugate provide the odds for an interaction with the observer happening here (0, 0, 0) in the **future**.

This novel interpretation is called Bell's future quantum mechanics.

1 New Views on Old Space-time

Start with a Minkowski space-time graph. All information that is local to the observer at the origin here-now is in the past lightcone. Quantum mechanics is non-local, ergo delete all local information - delete the past lightcone! The wave function has to reside in the space-like regions of space-time. The conjugate of the wave function goes on the other side of the lightcone. The product of the wave function and its conjugate is necessarily in the future at the spatial origin (here, or (0, 0, 0)). Quantum mechanics has always been about the future. What are the odds that an event will happen to an observer in the future? Bell's inequality is about the non-local nature of quantum mechanics. Deleting the past lightcone enforces non-locality. Space-like information can be used only to predict the future. This is the Bell's Future interpretation of quantum mechanics.

2 Historical Background

In 1935, Einstein, Polodsky, and Rosen (EPR)[6] proposed that variables hidden in the past lightcone could explain how quantum mechanics worked. The inherent uncertainty of quantum mechanics could be traded for something more real, variables that are hidden. This proposal was not an easy to dismiss given Einstein's stature. It took until the 1960s when John Bell found an inequality that could test if variables are hidden in the past lightcone or the entangled states of quantum mechanics where somehow real because quantum information was non-local.[3, 4] If one asks the same question the same way, both models make identical predictions. If questions are asked at a different angle, the hidden variable hypothesis is unchanged. Quantum mechanics says correlations between measurements become stronger. A huge experimental effort from the 1980s until today has always confirmed the same result: quantum mechanics is non-local and hidden variable models are wrong.

3 Totally-ordered and Disordered Sets in Space-time under Lorentz Transformations

In Einstein's first paper on special relativity in 1905, he shows how simultaneity is not an invariant under a Lorentz transformation.[7] While there may be an observer that says events A and B happened at the same moment in time, a second observer may say A happend before B while a third reports B happened before A. Is there something that all three observers can agree upon about events A and B, that is invariant under a proper Lorentz transformation? So long as the observers have put in the effort to agree about their choices in coordinates and the origin, then the three observers will all agree on the ordering in space of these events in space. If the first observer says A is left of B, then so do observers two and three. If events A and B were in the same location for one of the dimensions, they would remain together. A totally-ordered set means one can say exactly one of three things about any pair of numbers: one is bigger than the other, one is less than the other, or both have the same value. An axis on a graph is a totally-ordered set. Here we are thinking about pairs of events that can be connected by a straight line that runs through the origin. Under a Lorentz transformation, the time for these pairs can switch order depending on the intertial observer chosen. I will call this a disordered set of events in time for space-like separated events under proper Lorentz transformations. The measurements of space will form a totally-ordered set.

The same exercise can be repeated for all time-like pairs events that fall on a line running through the origin. These pairs of events will be totally-ordered in time: event A did happen before event B and all observers agree to that. If event A was simultaneous to event B, that will remain true for all possible inertial observers. To be time-like, simultaneous, and be on a line through the orgin requires that the spatial location of A is idential to B. What is disordered are measurements of space. If event A is located at the same place as event B for one observer, a different obserser could put A left of B. The third observer may see event A to the right of B, and so on.

Pairs of light-like events remain totally-ordered in both time and the three directions of space. Since everything in the light-cone travels at the same speed, there is no way for one event to "catch up" to another. Here is a summary:

Relation to Origin	space-time component	Ordering
space-like	t	disordered
	x_1	totally-ordered
	x_2	totally-ordered
	x_3	totally-ordered
time-like	t	totally-ordered
	x_1	disordered
	x_2	disordered
	x_3	disordered
light-like	t	totally-ordered
	x_1	totally-ordered
	x_2	totally-ordered
	x_3	totally-ordered

Why is this table relevant to the topic at hand? Consider what is meant by "causality". It is a Rube Goldberg machine at work: this happens, then that, finally the end. In other words, events are totally-ordered in time. That is possible for time-like and light-like events. Space-like events are disordered in time under Lorentz tranformations. Causality for sets of space-like events has to be fundamentally different that for time-like and light-like events.

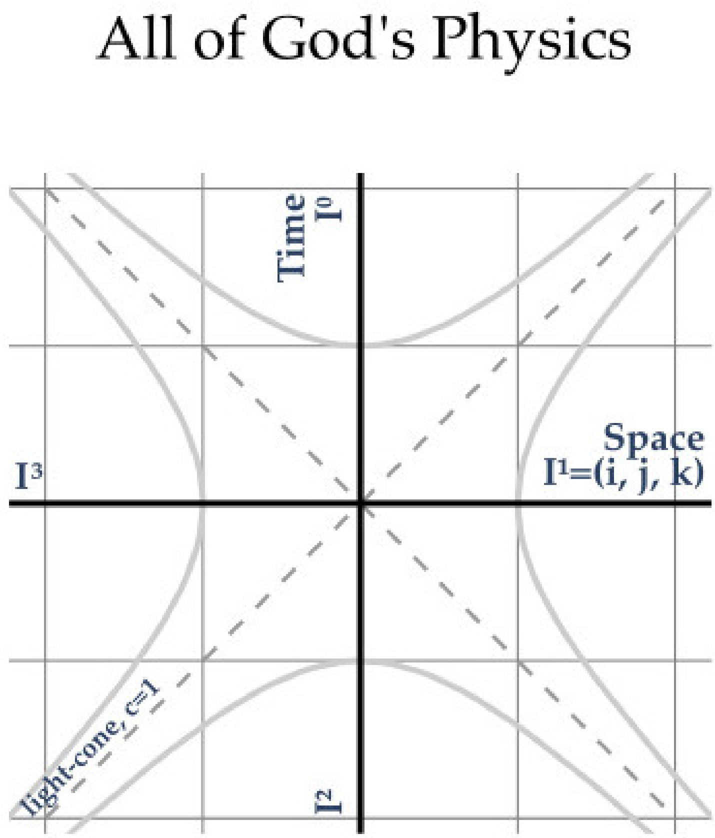


Figure 4.1: All of God's Physics

4 My Beliefs About It All in 3D Space + TimeThere is a small twist for the first and second conjugates. One way to calculate the first conjugate is to put in a factor of i before and after the quaternion, like so:

Einstein put Lorentz transformations to great use to solve difficult theoretical problems in physics. It was his math professor Herman Minkowski who recognized that Einstein was doing rotations not just in space, but in space-time. Here is a picture of all of space:

I hope the gentle reader is not offput by referencing a diety. The word choice was made because it is my belief that all of physics, both that that is currently known which is the vast majority, and that which remain unknown, must live only in 3D space + time, or space-time. I am more concerned with why parity is not conserved for beta decay than any biblical issue.

Noice how three spatial dimensions are written explicity in the space-time graph. Starting from studies done with five dimensions in the 1920s, research begun in the 1970s created a significant investigation into higher spatial dimensions. I believe all such work will have no lasting value. More recently, people have been championing a multi-verse thesis. A multi-verse has multiple space-times. Again, I believe all such work witll have no lasting value.

I am radical conservative circa 1960s in regards to precisely three dimensions for space and one for time.

4.1 Technical Tangent: quaternions

The previous section reveals that I am a 1908 Minkowski radical. He wrote[8]:

> Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.

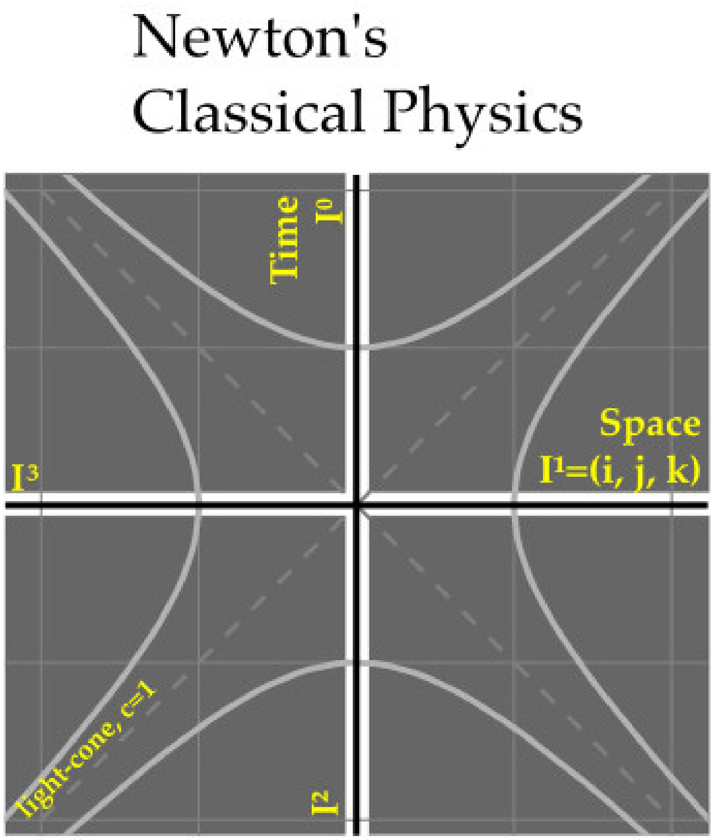
If an event in space-time is just a bag of numbers (a vector with scant structure), it is OK to ask if the bag can be expanded as research into higher dimensions does. If an event is just one number, the bag cannot be expanded. I study a kind of number with that property, called the quaternions. A sublte hint appears on how the axes are labeled with power series of the 3-vector I (I^0 for the positive reals, I^1 for the imaginaries, I^2 for the negative reals, I^3 for the negative imaginaries). I like to algegraically enforce Minkowski's vision.

Quaternions are not central to Bell's future quantum mechanics. Still, while the car of theoretical physics is in for repairs, one might as well consider a complete overhaul.

In summary, space-time is everything we know and everything we do not know, all on the same stage.

5 Newton Through Subtraction

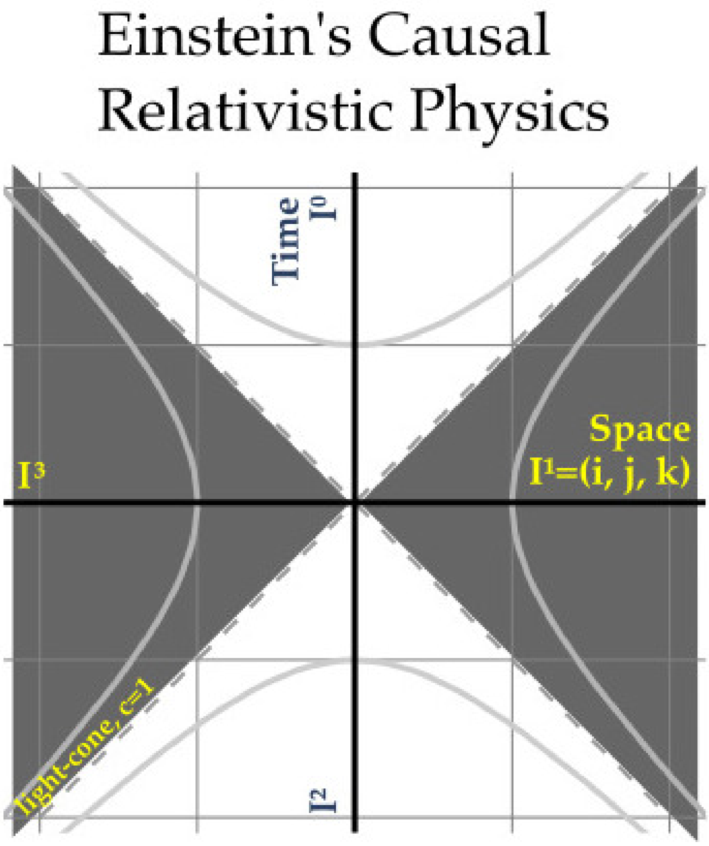
Most of space-time gets subtracted for Newton's classical physics.



Space is abosulte. Time is absolute. There is no way in Newtonian physics to rotate space into time. This is the physics we experience everyday.

6 Einstein's Causal Relativistic Physics

The only kinds of events that can change an observer at the origin are events from the past lightcone.



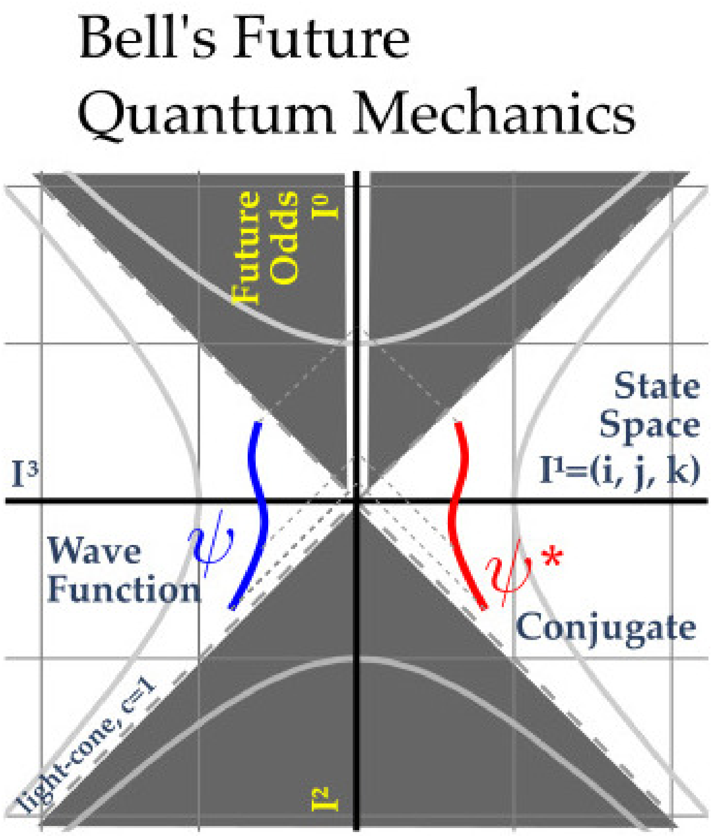
Einstein was adroit at working with the space-like regions, realizing for example that events that are simultaneous in one reference frame will not be so in another. If one decides to be restricted to the study causality, that is the reason to black out the space-time regions. Why did something happen? The answer is in the past lightcone, not the space-like region.

7 Bell's Future Quantum Mechanics

This is from a Wikipedia discussion of EPR paper:

> The 1935 EPR paper condensed the philosophical discussion into a physical argument. The authors claim that given a specific experiment, in which the outcome of a measurement is known before the measurement takes place, there must exist something in the real world, an "element of reality", that determines the measurement outcome. They postulate that these elements of reality are, in modern terminology, local, in the sense that each belongs to a certain point in spacetime. Each element may, again in modern terminology, only be influenced by events which are located in the backward lightcone of its point in spacetime (i.e., the past). These claims are founded on assumptions about nature that constitute what is now known as local realism.

It was the clause "only be influenced by events which are located in the backward lightcone" that caught my attention. If there are no hidden variables as shown by experiments, remove any possibility.

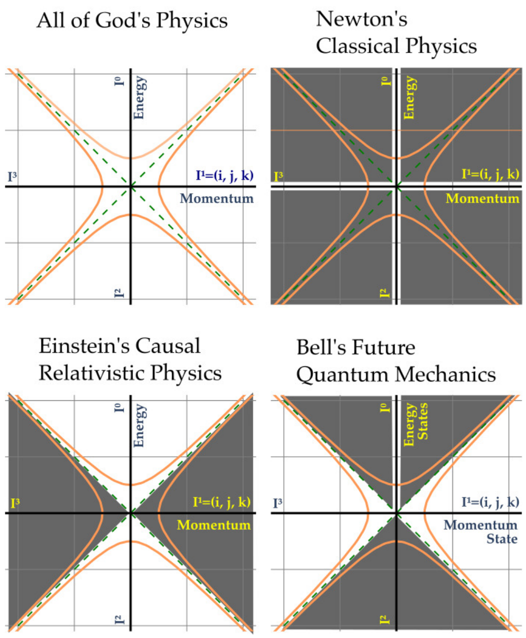


The past lightcone has been darkened to indicate it is not part of quantum mechanics - only non-local-to-the-observer events are. Notice how little of the time-like future is included: just the time axis with the spatial terms set to 0, 0, 0.

Einstein causality and Bell's future combine to cover all of space-time. Both relativity and quantum mechanics were born and matured in the same time window, and at for Einstein, in the same mind in the same Spring/Summer of 1905.

8 Repeat the Exercise for Tangent Spaces

Space-time records where-when things are: location, location, location at one moment in time. Space-time formally has no information about change. Change lives in tangent spaces. Which tangent space is used determines what kind of change is under study. The most common one is energy-momentum. Tangent spaces can also be broken up into the same four types: all, classical, relativistic, and quantum:



Imagine one were to study the classical motion of a rock. There would be energy and momentum at the point in space-time where the rock happened to be. Everywhere-when else in space-time, the energy-momentum space would be zero. These zeroes are usually ignored, so the topic of tangent spaces only appears at the graduate-level. It makes the switch to continuous fields seem mystical. Instead, the difference between the two is more like discrete and continuous for energy-momentum.

Physicists have studied all combinations of the base space space-time with the tangent space energy-momentum. For example, there is both classical and relativistic quantum mechanics.

8.1 Uncool Sidebar: The Base Space is the Base

The base space, space-time, cannot be changed by anything. I appreciate that this clear statement will be violently rejected by those who have made a serious study of Einstein's general relativity. Tens of thousands of times it has been repeated: gravity bends space-time. I am not in denial of the words. I do feel compelled to at least question the link from words to the more precise math. Gravity alters a tangent space of space-time as seen by the dt and dR in metric solutions. Space-time has Lorentz symmetry and its origin. Gravity and energy-momentum have Poincare symmetry. Summing up all the changes in all the tangent spaces results in a curved path in space-time. All the change happens in the tangent space. We should be saying the tangent space is curved then summed, not that the base space is curved.

9 Momentum versus a Momentum State

Why use momentum in relativity, but momentum states in quantum mechanics? Momentum from the past lightcone can change the motion of the observer at the origin. The entire chain of events leading to that change in the observer can be known. A space-like momentum state is different. Momentum states may never change the observer at the origin, here-now. The precise odds of a momentum state changing the momentum of an observer can be calculated.

In the future, if an interaction does occur, it will change the path of the observer the usual amount. The entire chain of events leading to this momentum change cannot be known because they are space-like separated. The observer is *necessarily* blind-sided by a momentum state.

The same story applies to energy versus an energy state. Observers can absorb energy from the past lightcone and heat up. Observers cannot absorb energy from an energy state as it is too far away. The can in the futur absorb the energy to the same effect. We calculate the exact odds of that happening to the observer at the spatial origin in the future.

10 The Wave Function

The wave function is a set of space-like energy-momentum states. Each state may not have a time-like relationship to the observer at the origin, here-now. Each state of the wave function can have a time-like relationship with other states in the wave function. Light-like relationships are not addressed for the moment as that is a refinement one will have to include with care later.

For a complex-valued wave function, the conjugate is simple to construct. The product of a wave function and its conjugate evaluates to a positive real number. If properly normalized, the postive number is the odds of an interation happening. Nothing unusual is happening under the Bell's future interpretation, all calculations will be the same.

10.1 Dull Quaterion Series Quantum Mechanics

Quaternion quantum mechanics has been studied and presented in a book-length form by Stephen Adler. The topic has been commented on in a December 2018 blog by Scott Aaronson where he came to the conclusion that quaternion quantum mechanics was a "complete dumpster fire" because it would allow superluminal transfer of information. I agree, any algebraic system that allows superluminal transformation is boring and deserves no futher study. I was suprised that this flaw was known to Adler as he admitted to Aaronson.

In a rapid exchange I had with Aaronson, I came up with the idea of "point-one-way" quaternions. Pick an arbitrary direction and stick with that for all calculations. Aaronson agreed it would work. He just thought it was so dull it did not even deserve a new name.

As I considered it more, a better name would have been "point-with-precision" quaternion series quantum mechanics. In the lab, physics experiments are reknown for their precision of the experimental apperatus. It is common to use tables that isolate the vibrations of the surroundings from the experiment. The precision of location known at the bench should also apply to the math used. Quaternions that point in the same direction commute. A quaternion series is not a division algebra like the quaternions. Instead it is a semi-group with inverses. A semi-group has more than one inverse. Two non-zero quaternion series can be orthogonal, so the inner product is zero.

For quaternion-valued wave functions, the conjugate has a physical meaning: it is a mirror reflection in space. Why do so? The product of the wave function and its mirror reflection is a here-future value, (0, 0, 0) for the 3-vector and a positive real number. If properly normalized, the real value is the odds of seeing an interaction. It is the simple, physical interpretation of an otherwise abstraction notion of a complex-valued wave function that I see as a benefit worthy of exploration.

The Bell's future quantum mechanics interpretation could be embraced with complex-valued quantum mechanics instead of quaternion series quantum mechanics. As a physicist, I prefer the physical interpretation available with quaternion series.

11 Entagled States

As an exercise for quaternion series quantum mechanics, I figured out how to prove the CHSH inequality which is one way to test for the non-local nature of quantum mechanics.[5] The first part of the exercise is to use quaternions of the form $(a, b, 0, 0)$, in other words the standard complex-valued calculation.[9] To generalize to quaternions, all that is needed is that the spatial 3-vector has a norm of one. Here is the entangled state used in the calculation:

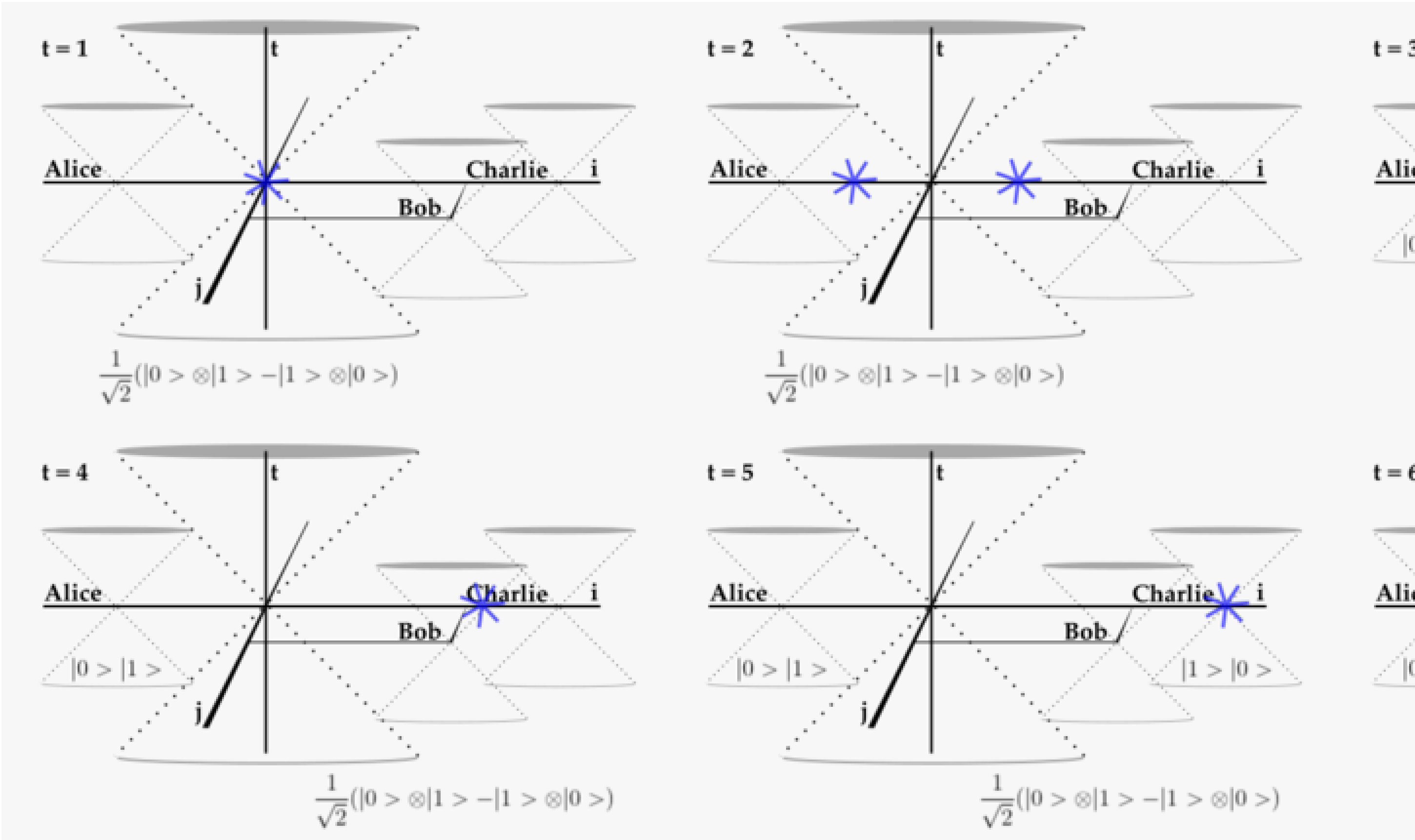
$$|\psi_s>= \frac{1}{\sqrt{2}}(|0> \otimes|1> -|1> \otimes|0>)$$

How can one represent this information on a Minkowski space-time diagram? What does it mean to have three observers, Alice who sees the state, Bob who does not, or Charlie who does?

There are four lightcones to keep track of in space-time: The Originating lightcone that creates the entangled state and the three for observers Alice, Bob, and Charlie. There are six moments in space-time that will be depicted:

1. The moment the entangled state is created
2. The signals first approaching the three observers
3. Alice getting the signal
4. Bob missing the signal
5. Charlie getting the signal
6. After the signal is found by Alice and Charlie

Here are all six states:



The largest lightcone is where the entangled state with two qubits is created at time $t = 1$. The two qubits go their separate ways along the i axis at time $t = 2$. Notice how they are space-like separated. That is one consequence of Bell's inequality: the qubits need to have a space-like relationship to necessariy be non-local. One qubit arrives at observer Alice at time $t = 3$ where she determines that the state she gets to measure is $|0>|1>$.

Bob will never see any signals that Alice does. Notice how the qubits travel along $i = 1$, $j = 0$, but Bob has a non-zero j value. This is consistent with how experiments are done in a lab. Everything on a light table has to be precisely aligned before one collects correlation data. Experimentally, this is not a surprise. What is different here is that with quaternion series quantum mechanics, that same issue can be seen in the algebra. Of course the experimentalist could place a mirror so the signal does get to Bob. In that case, the mathematician would do a spatial rotation on the entangled state of precisely the same form. Changes at the bench can be accounted for in the math.

Charlie is able to see the qubit at time $t = 5$, measuring a state of $|1>|0>$. The two qubits have been absorbed by Alice and Charlie, so there is no more entagled state at time $t = 6$, just two observerations by two observers.

The proof of non-locality remains a subtle craft. If the same question about the same event is asked the same way by two observers, one cannot distinguish between hidden local-variable theories and non-local quantum mechanics. Only by collecting data when there are differences between the measuring angle for Alice and Charlie can it be shown that the math of the entangled state must govern the description of the two qubits, even after one qubit is known to Alice. It remains about the odds *in the future* that Alice and Charlie see signals depending on the angle. I suspect few will care about Bob who collects no data but whose sad plight can be explained using quaternion series instead of complex numbers to form the Hilbert space needed in quantum mechanics.

12 Interpretations of Quantum Mechanics

There are at least 20 intepretations of quantum mechanics. Nearly all of them make the same predictions as does this one. I have seen Sean Carroll take a poll of graduate students to find their favorite. This is not the way physics works. Physics is a contact sport with only one eventual winner.

Physics by subtraction defines areas of study. Newton's classical physics uses only a narrow width around the axes. Causality in special relativity uses only the past lightcone. By contrast, quantum mechancis uses nothing from the past lightcone. Quantum mechanics uses space-like states to calculate the odds of interactions in the future.

Bell's future quantum mechanics looks bright. I hope this idea goes viral in a good way.

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