Quantum Mysteries for Anybody: Solved

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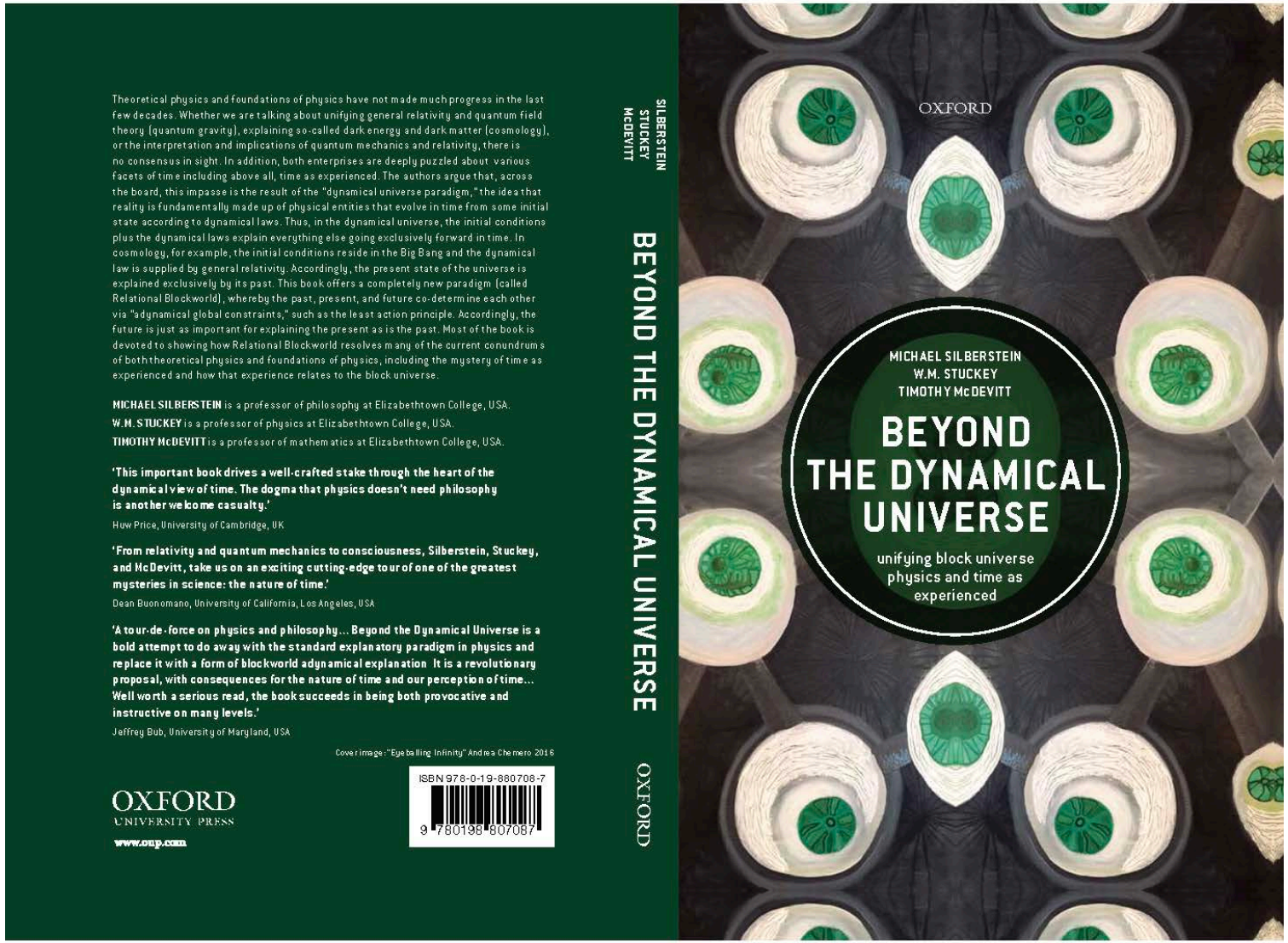
In 1981, Mermin published a now famous paper titled, “Bringing home the atomic world: Quantum mysteries for anybody” that Feynman called, “One of the most beautiful papers in physics that I know.” Therein, he presented the “Mermin device” that illustrates the conundrum of entanglement per the Bell spin states for the “general reader.” He then challenged the “physicist reader” to explain the way the device works “in terms meaningful to a general reader struggling with the dilemma raised by the device.” Herein, I show how the principle of **conservation per no preferred reference frame** (NPRF) answers that challenge, but still leaves a mystery for those who seek constructive explanation via hidden variables or causal mechanisms.

For an overview of adynamical, constraint-based explanation resolving puzzles, problems, and paradoxes throughout modern physics see:



Theoretical physics and foundations of physics have not made much progress in the last few decades. Whether we are talking about unifying general relativity and quantum field theory (quantum gravity), explaining so-called dark energy and dark matter (cosmology), or the interpretation and implications of quantum mechanics and relativity, there is no consensus in sight. In addition, both enterprises are deeply puzzled about various facets of time including above all, time as experienced. The authors argue that, across the board, this impasse is the result of the "dynamical universe paradigm," the idea that reality is fundamentally made up of physical entities that evolve in time from some initial state according to dynamical laws. Thus, in the dynamical universe, the initial conditions plus the dynamical laws explain everything else going exclusively forward in time. In cosmology, for example, the initial conditions reside in the Big Bang and the dynamical law is supplied by general relativity. Accordingly, the present state of the universe is explained exclusively by its past. This book offers a completely new paradigm (called Relational Blockworld), whereby the past, present, and future co-determine each other via "adynamical global constraints," such as the least action principle. Accordingly, the future is just as important for explaining the present as is the past. Most of the book is devoted to showing how Relational Blockworld resolves many of the current conundrums of both theoretical physics and foundations of physics, including the mystery of time as experienced and how that experience relates to the block universe.

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TIMOTHY McDEVITT is a professor of mathematics at Elizabethtown College, USA.

'This important book drives a well-crafted stake through the heart of the dynamical view of time. The dogma that physics doesn't need philosophy is another welcome casualty.'
Huw Price, University of Cambridge, UK

'From relativity and quantum mechanics to consciousness, Silberstein, Stuckey, and McDevitt, take us on an exciting cutting-edge tour of one of the greatest mysteries in science: the nature of time.'
Dean Buonomano, University of California, Los Angeles, USA

'A tour-de-force on physics and philosophy... Beyond the Dynamical Universe is a bold attempt to do away with the standard explanatory paradigm in physics and replace it with a form of blockworld adynamical explanation It is a revolutionary proposal, with consequences for the nature of time and our perception of time... Well worth a serious read, the book succeeds in being both provocative and instructive on many levels.'
Jeffrey Bub, University of Maryland, USA

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BEYOND THE DYNAMICAL UNIVERSE

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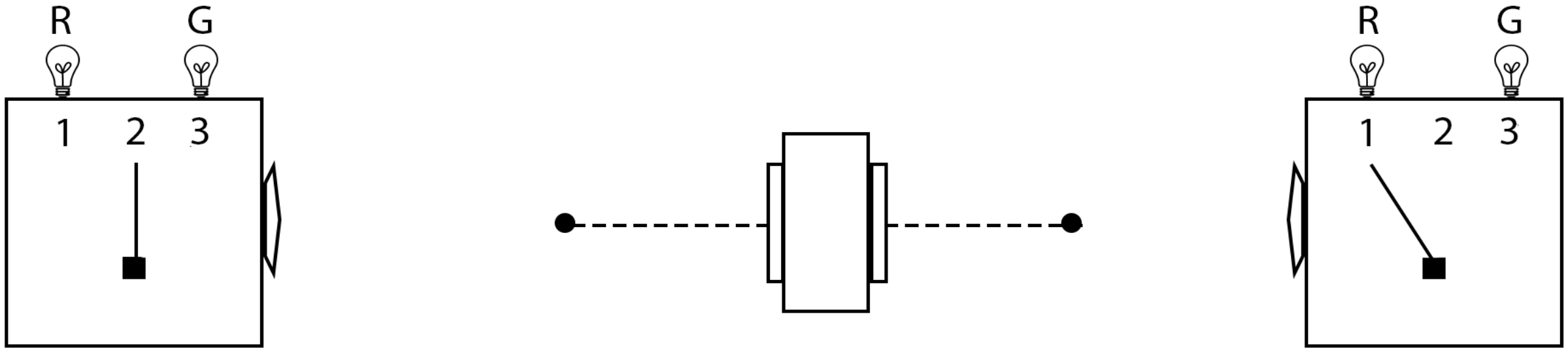
BEYOND THE DYNAMICAL UNIVERSE

unifying block universe physics and time as experienced

Outline

1. Review Mermin Device
2. SU(2) Symmetry of Bell Spin States, SO(3) Invariance of SG Spin Measurement Outcomes, and Conservation of Spin Angular Momentum
3. Average-Only Conservation
4. Conservation per No Preferred Reference Frame (NPRF)
5. NPRF in Special Relativity and Quantum Mechanics

Mermin Device



The Mysterious Facts

Fact 1: In any trial when Alice and Bob have same settings ("case (a)"), they always get the same outcomes (½ RR and ½ GG).

Fact 2: In all trials for which they have different settings ("case (b)"), Alice and Bob's outcomes are the same ¼ of the time ($\frac{1}{8}$ RR and $\frac{1}{8}$ GG).

Mermin's Constraints:

1. The particles cannot "know" how they will be measured (no retrocausality).
2. The particles cannot exchange information between the spacelike separated detection events (no superluminal communication).

So, how to guarantee Fact 1? Particles' outcomes for each possible setting are determined before the particles leave the source, i.e., they have "instruction sets."

Mermin says of instructions sets, "It cannot be proved that there is no other way, but I challenge the reader to suggest any."

But, if you use instruction sets to account for Fact 1, you must get the same outcomes in more than $\frac{1}{3}$ of the case (b) trials (Bell inequality), in violation of Fact 2. Thus, Mermin has explained the mystery of entanglement per the Bell spin states for a "general reader."

He then challenged the "physicist reader" to explain the way the device works "in terms meaningful to a general reader struggling with the dilemma raised by the device."

Based on Spin

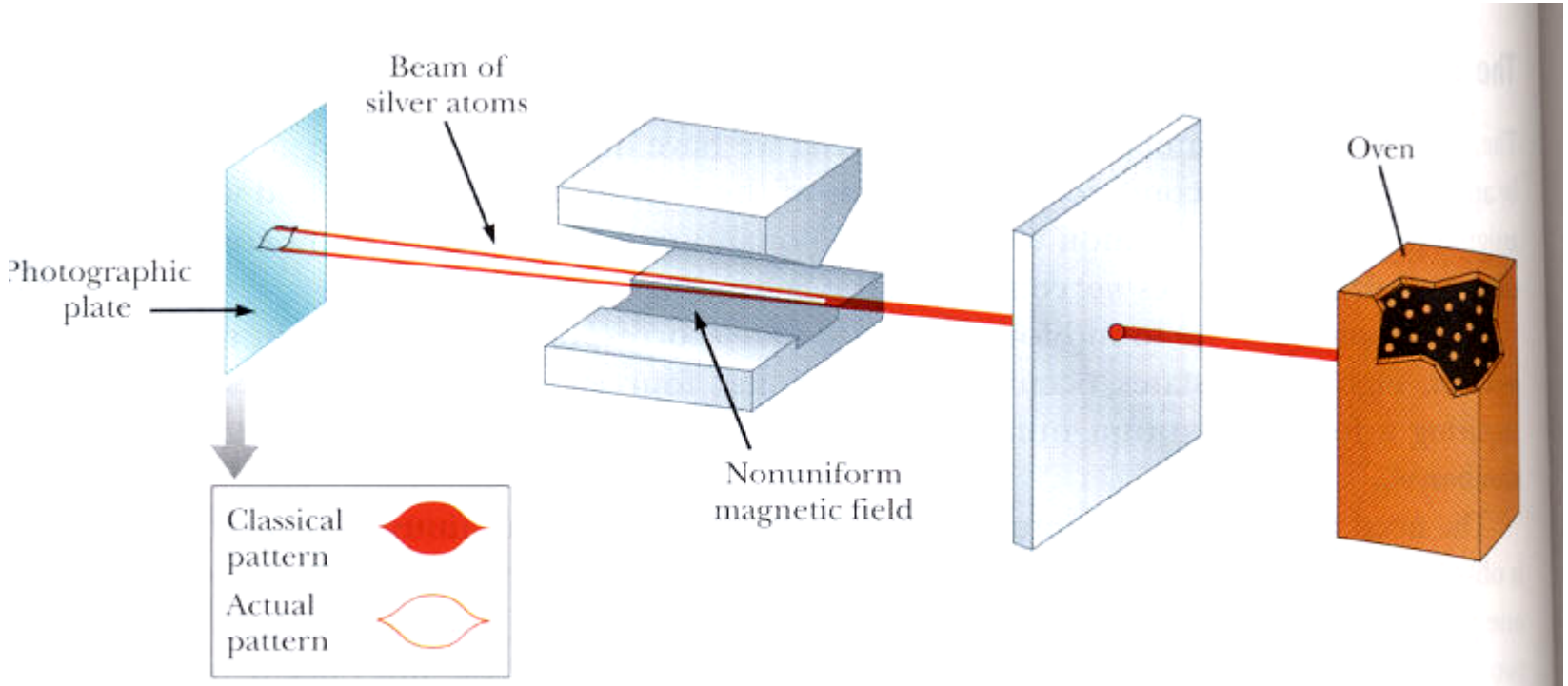


Figure 42.17 The technique used by Stern and Gerlach to verify space quantization. A beam of silver atoms is split in two by a nonuniform magnetic field.

Bell Spin States

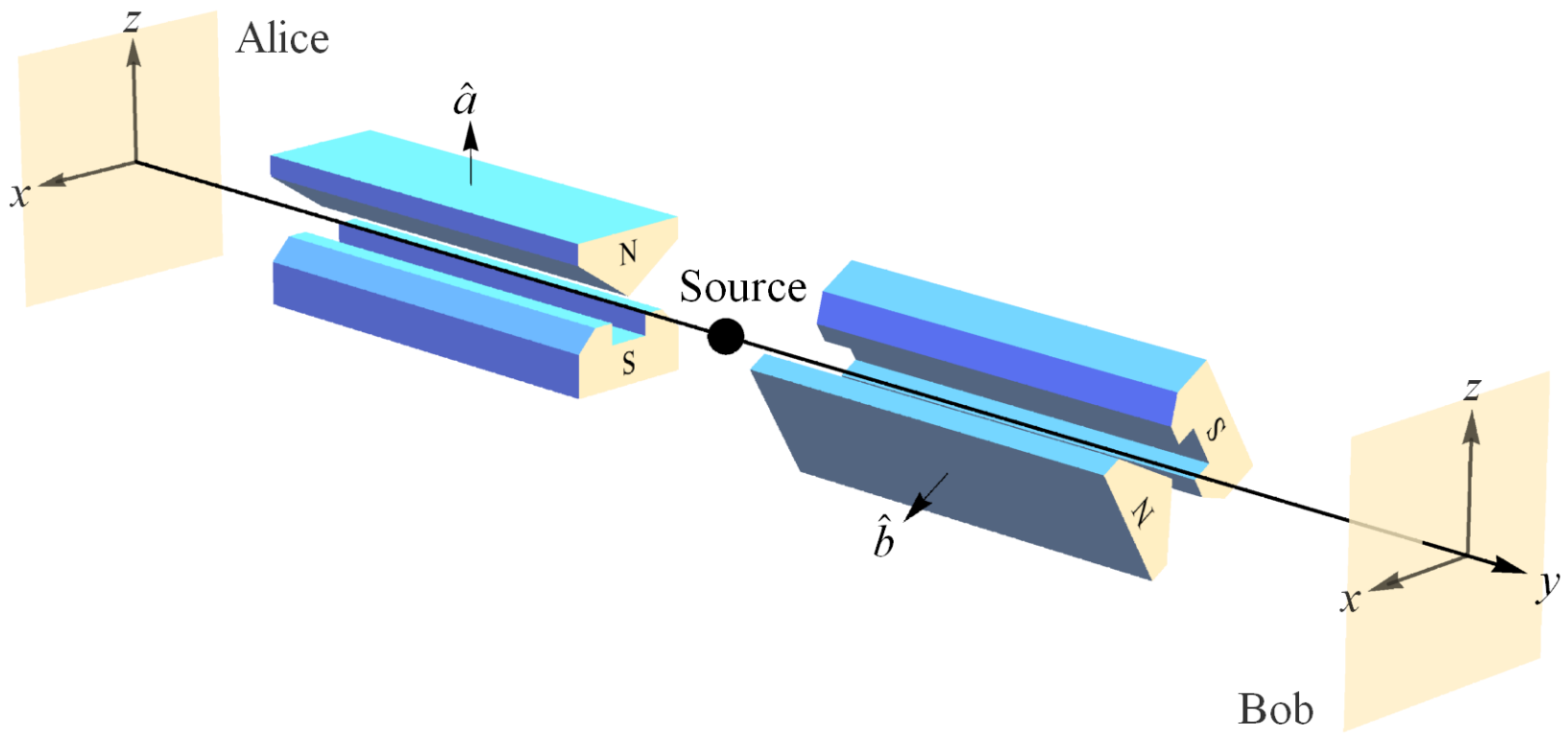
$$|\psi_-\rangle = \frac{|ud\rangle - |du\rangle}{\sqrt{2}}$$

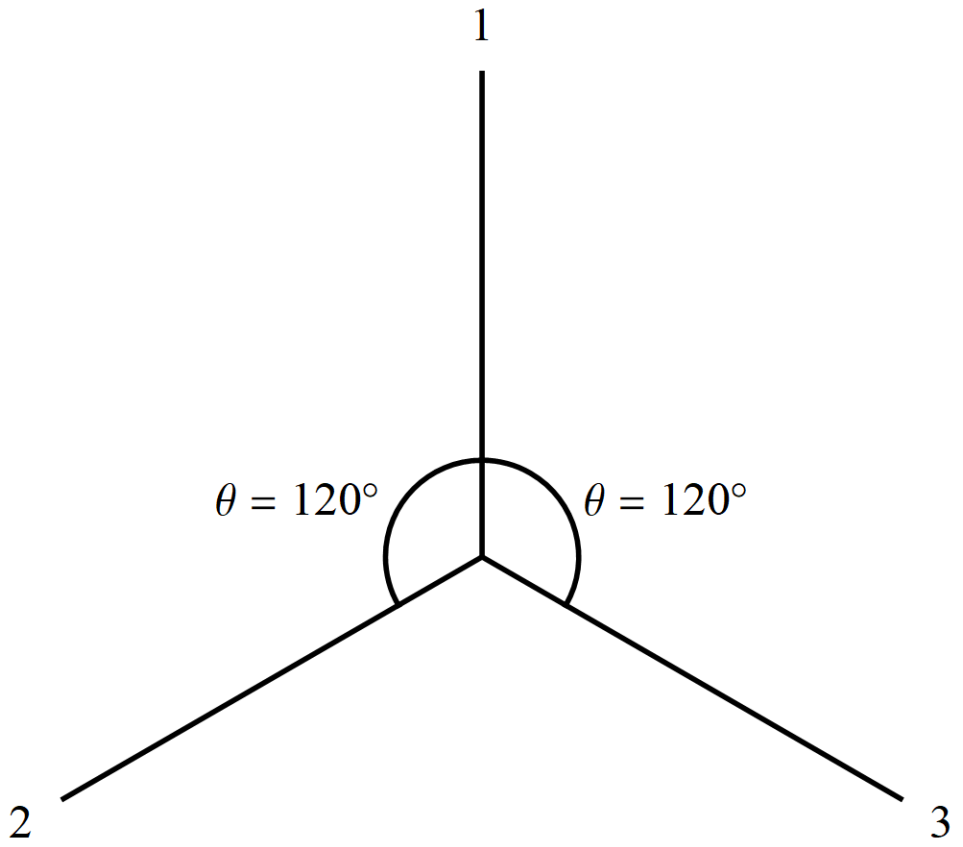
$$|\psi_+\rangle = \frac{|ud\rangle + |du\rangle}{\sqrt{2}}$$

$$|\phi_-\rangle = \frac{|uu\rangle - |dd\rangle}{\sqrt{2}}$$

$$|\phi_+\rangle = \frac{|uu\rangle + |dd\rangle}{\sqrt{2}}$$

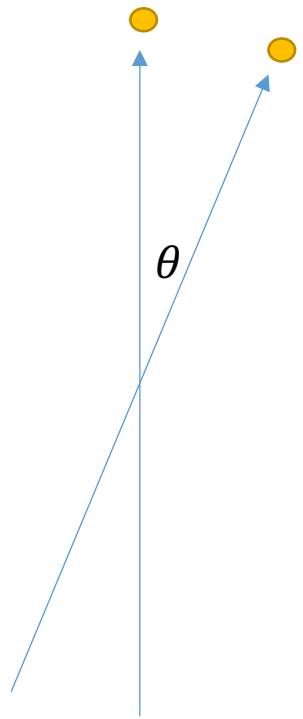
Here, Alice measures σ_1 at $\hat{a}$ in the *xz*-plane and Bob measures σ_2 at $\hat{b}$ in the *xz*-plane





Possible planar orientations for Alice and Bob's SG magnets for Mermin device in the plane of symmetry.

Mermin device maps to spin triplet states. Here is an empirical overview of how outcomes correlate. Blue arrows denote orientation of Alice and Bob's SG magnets. Yellow dots indicate the outcomes.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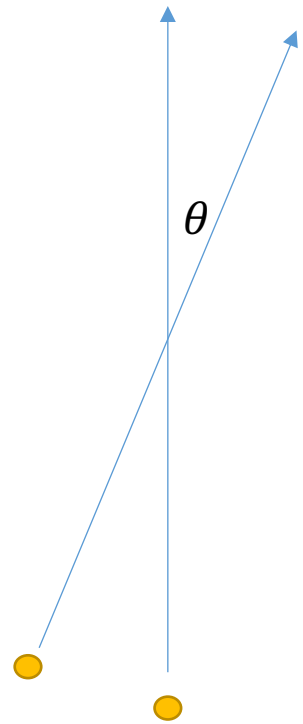
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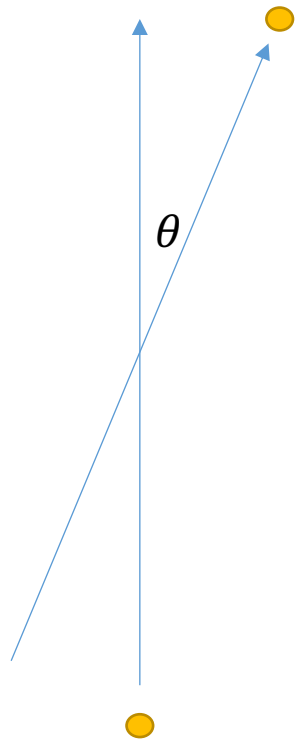
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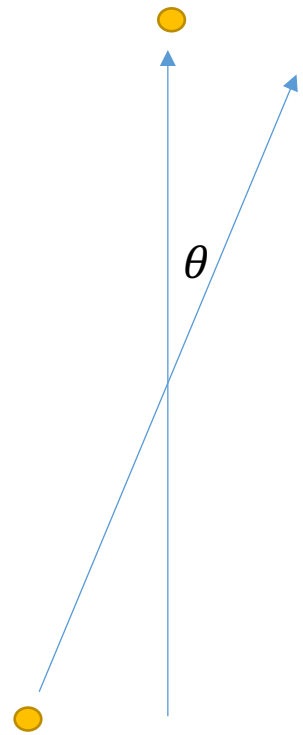
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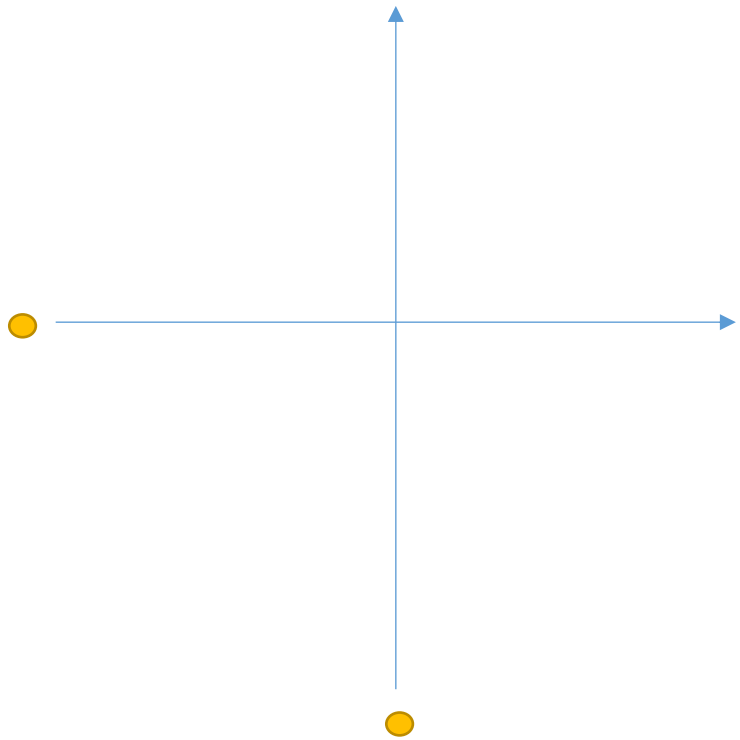
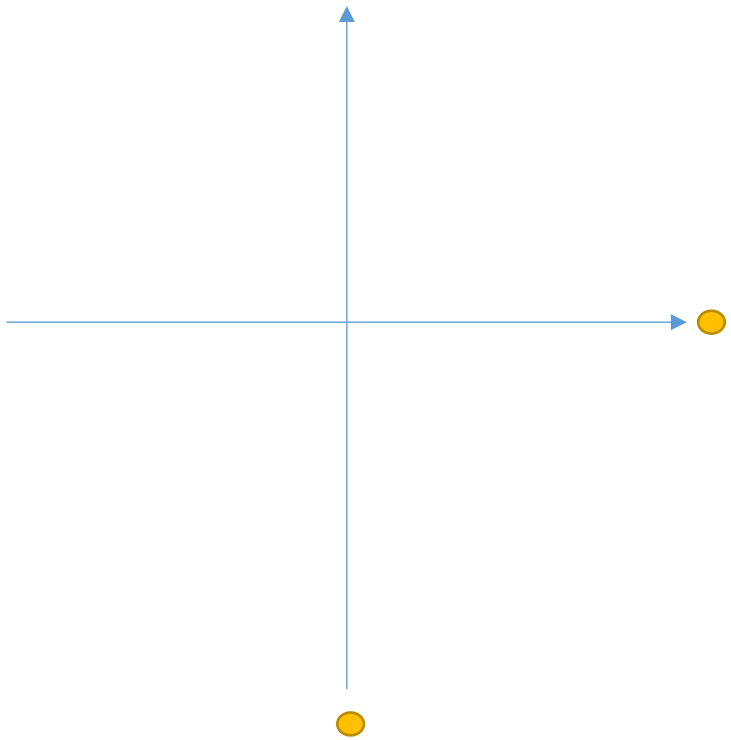
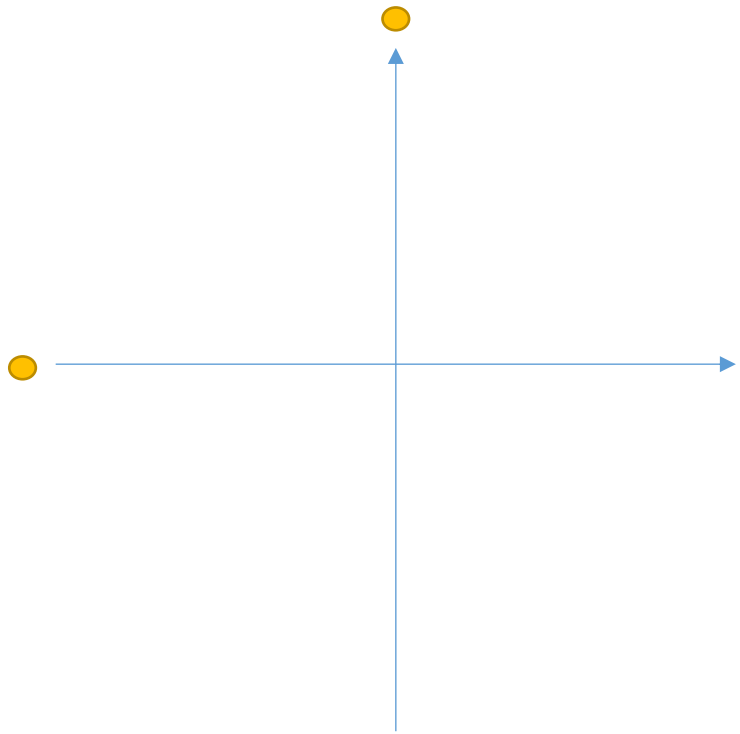
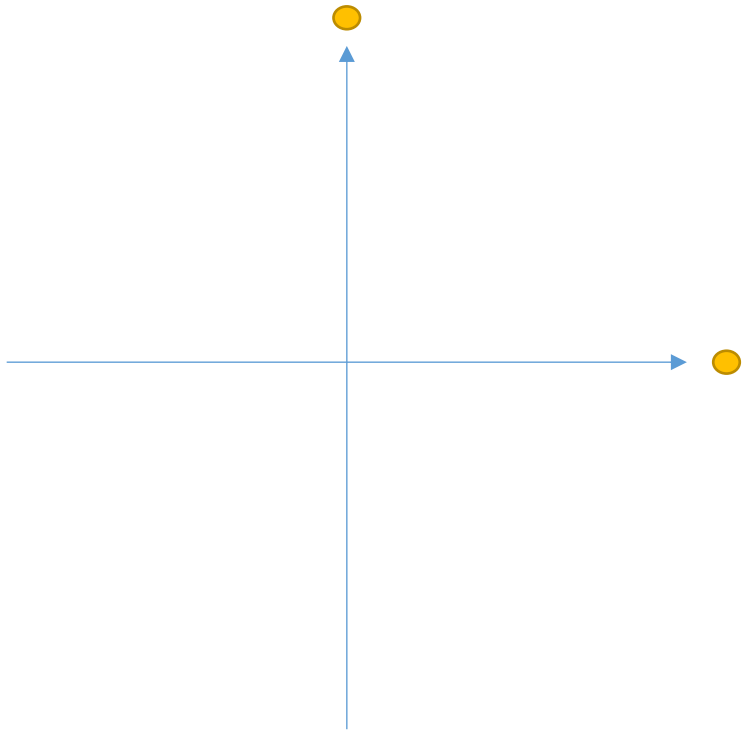








Correlation function = $\cos\theta$

Leads to violation of Bell's inequality and accounts for Facts 1 and 2

The Correlation Functions:

$$\langle\psi_-|\sigma_1\sigma_2|\psi_-\rangle = -a_xb_x - a_yb_y - a_zb_z$$
$$\langle\psi_+|\sigma_1\sigma_2|\psi_+\rangle = a_xb_x + a_yb_y - a_zb_z$$
$$\langle\phi_-|\sigma_1\sigma_2|\phi_-\rangle = -a_xb_x + a_yb_y + a_zb_z$$
$$\langle\phi_+|\sigma_1\sigma_2|\phi_+\rangle = a_xb_x - a_yb_y + a_zb_z$$

SU(2) Symmetries:

$e^{i\Theta\sigma_x}$ $e^{i\Theta\sigma_y}$ $e^{i\Theta\sigma_z}$

$e^{i\Theta\sigma_z}$

$e^{i\Theta\sigma_x}$

$e^{i\Theta\sigma_y}$

The spin singlet state is $-\hat{a}\cdot\hat{b} = -\cos\theta$ in all planes (S = 0)

The spin triplet states are $\hat{a}\cdot\hat{b} = \cos\theta$ in their plane of symmetry (S = 1)

SO(3) invariance for SG spin measurement outcomes in real space corresponds to SU(2) symmetry of Bell spin states in Hilbert space.

Consider the correlation function for all trials where Alice's SG setting is α and Bob's is β.

$$\langle \alpha, \beta \rangle = \frac{(+1)_A(-1)_B + (+1)_A(+1)_B + (-1)_A(-1)_B + \ldots}{N}$$

Now organize this according to Alice's outcomes (partition per Alice's equivalence relation).

$$\langle \alpha, \beta \rangle = \frac{(+1)_A(\sum \mathrm{BA}+) + (-1)_A(\sum \mathrm{BA}\text{-})}{N}$$

So, we need to explain to the "general reader" why Bob's outcomes average as they do for each of Alice's +1/-1 outcomes in case (b). [Note: Case (a) is explained directly by our SO(3) conservation, so it's not the source of the mystery.]

$$\langle \alpha, \beta \rangle = \frac{1}{2}(+1)_A\overline{BA+} + \frac{1}{2}(-1)_A\overline{BA-}$$

Spin Singlet State

When making the same measurement (SG magnets oriented in the same direction, case (a), Alice and Bob in same reference frame) we have

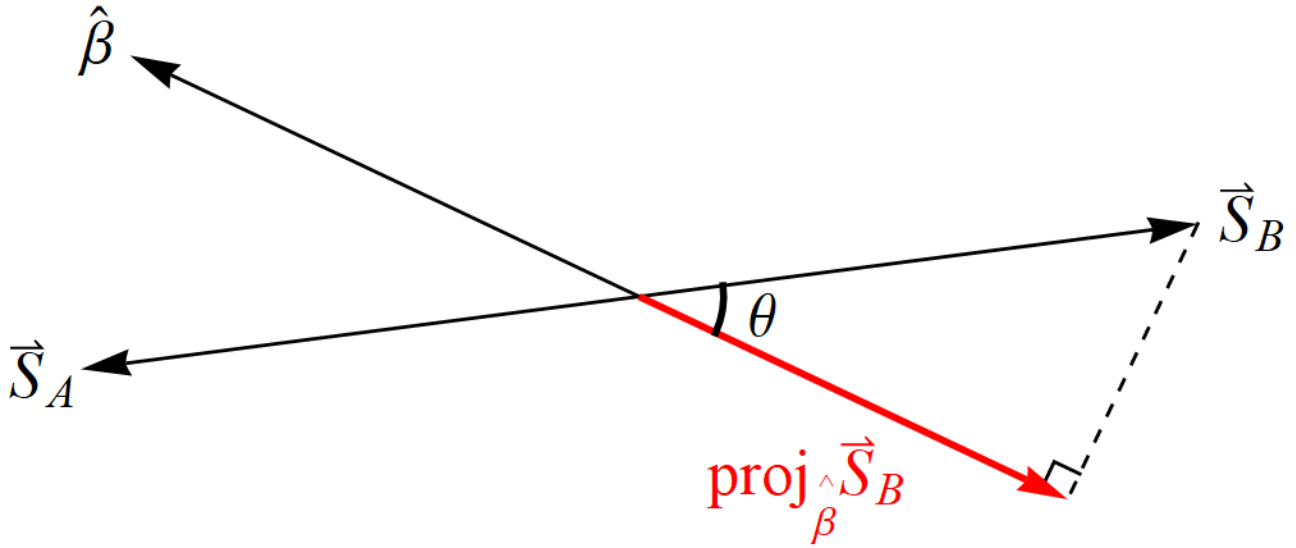
$$\vec{S}_A = +1\hat{\alpha} \quad \text{and} \quad \vec{S}_B = -1\hat{\alpha}$$

So, if Bob makes a different measurement (case (b), along $\hat{\beta}$) , Alice can argue that Bob should obtain

$$\vec{S}_B \cdot \hat{\beta} = -1\hat{\alpha} \cdot \hat{\beta} = -\cos\theta$$

Of course, Bob only obtains +1 or –1, no fractions, but suppose Bob's outcomes *average* the required $-\cos(\theta)$.

This figure shows what does *not* happen. Bob only measures +1 or -1, no fractions.



$$\overline{BA+} = -\cos(\theta)$$

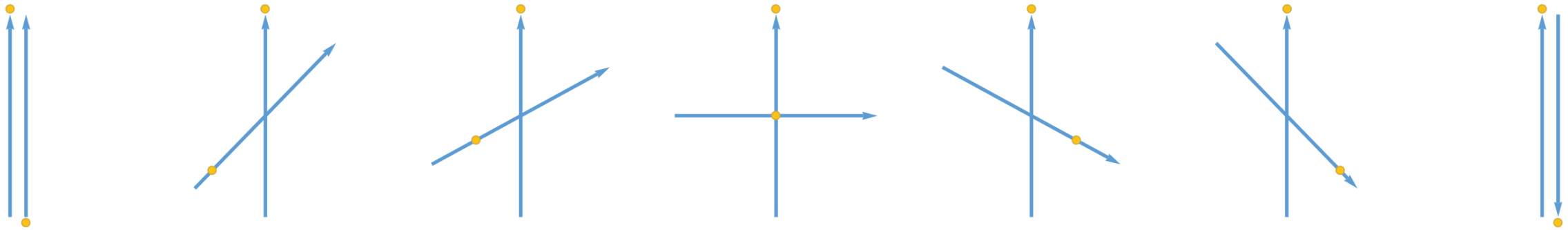
Likewise, for Alice's $(-1)_A$ results we have

$$\overline{BA-} = \cos(\theta)$$

And this leads to the quantum correlation function that accounts for the mystery of entanglement per the spin singlet state. Note: This is simply a mathematical fact that maps to an empirical fact.

$$\langle \alpha, \beta \rangle = \frac{1}{2}(+1)_A(-\cos(\theta)) + \frac{1}{2}(-1)_A(\cos(\theta)) = -\cos(\theta)$$

Average View for Spin Singlet State



This is what you would expect for *each* trial, given the SO(3) conservation in case (a). Indeed, the end two configurations (when in same reference frame) do obtain on a trial-by-trial basis. But, the others (when in different reference frames, case (b)) only obtain *on average*.

Spin Triplet States

When making the same measurement (SG magnets oriented in the same direction, case (a), Alice and Bob in same reference frame) we have

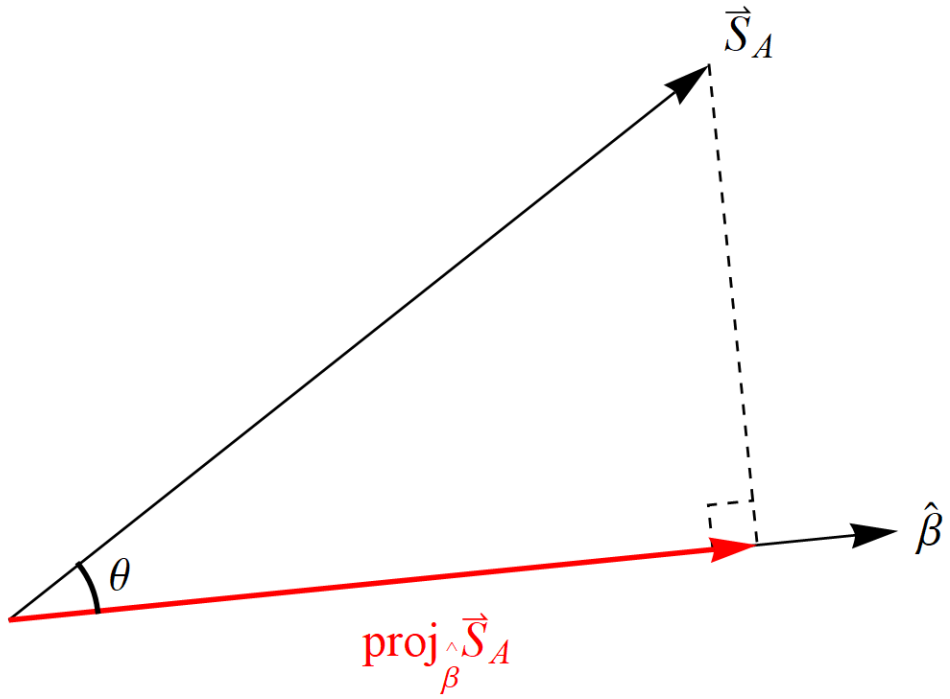
$$\vec{S}_A = \vec{S}_B = +1\hat{\alpha}.$$

So, if Bob makes a different measurement (case (b), along $\hat{\beta}$) , Alice can argue that Bob should obtain

$$\vec{S}_B \cdot \hat{\beta} = +1\hat{\alpha} \cdot \hat{\beta} = \cos\theta$$

Of course, Bob only obtains +1 or –1, no fractions, but suppose Bob's outcomes *average* the required $\cos(\theta)$.

Again, this figure shows what does *not* happen. Bob only measures +1 or -1, no fractions.



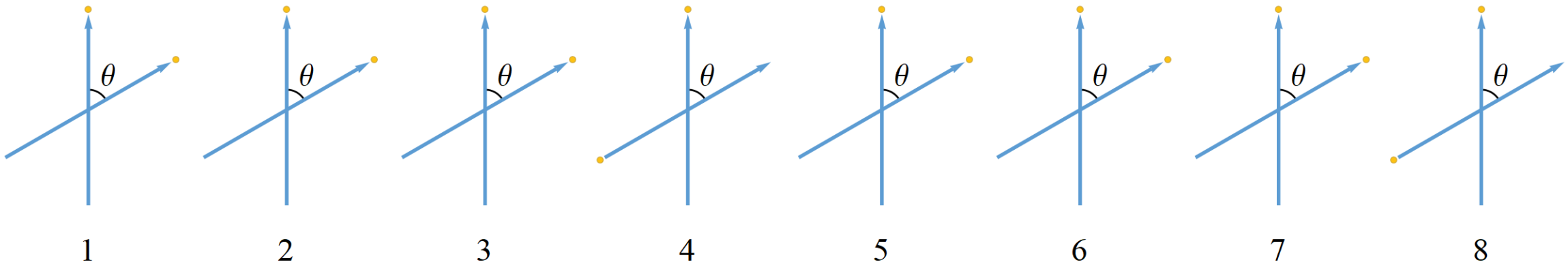
$$\overline{BA+} = \cos(\theta)$$

Likewise, for Alice's $(-1)_A$ results we have

$$\overline{BA-} = -\cos(\theta)$$

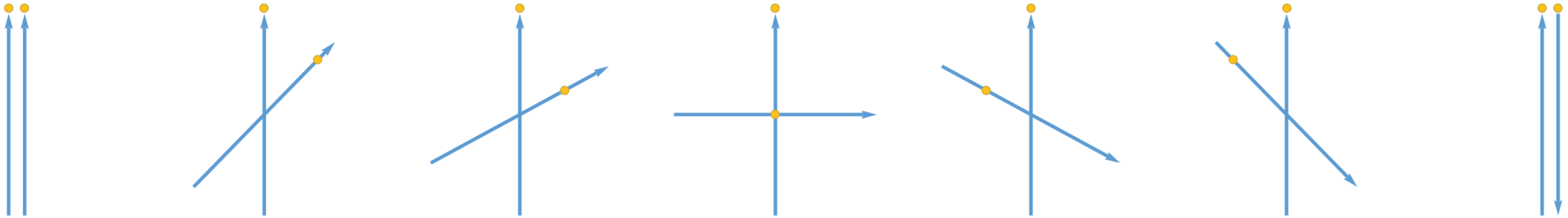
Again, this leads to the quantum correlation function that accounts for Facts 1 and 2 for the spin triplet states.

$$\langle \alpha, \beta \rangle = \frac{1}{2}(+1)_A(\cos(\theta)) + \frac{1}{2}(-1)_A(-\cos(\theta)) = \cos(\theta)$$



Average-only conservation in different reference frames (case (b)) leads to correlation function of $\cos\theta$ for the triplet states. In this example, we see that Bob's +1/-1 outcomes average $\cos 60^o = \frac{1}{2}$ corresponding to Alice's +1 outcome.

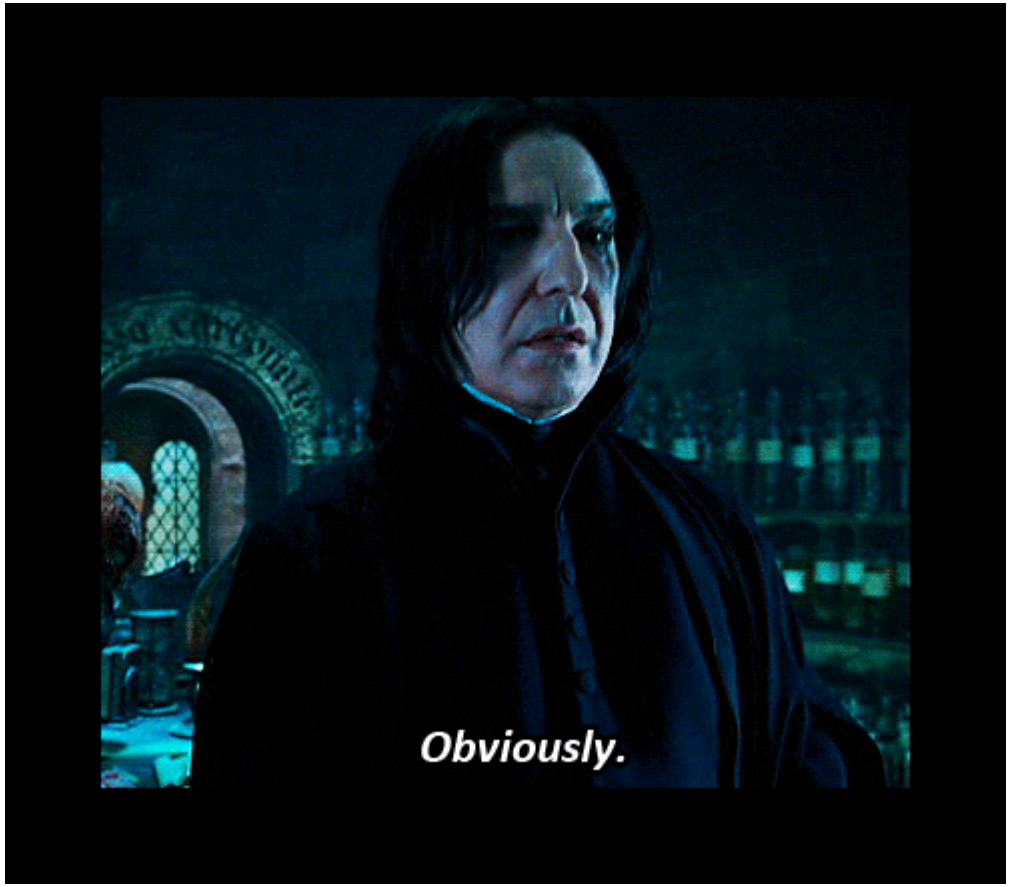
Average View for Spin Triplet States



Average-only conservation is a mathematical fact that maps to the empirical Facts 1 and 2 of the Mermin device.

Are We Done?

A ``shut-up-and-calculate'' physicist is typically satisfied with average-only conservation as the explanation of Facts 1 and 2, i.e., average-only conservation is the explanans. In contrast, the foundationalist finds average-only conservation to be an articulation of the mystery (explanandum).



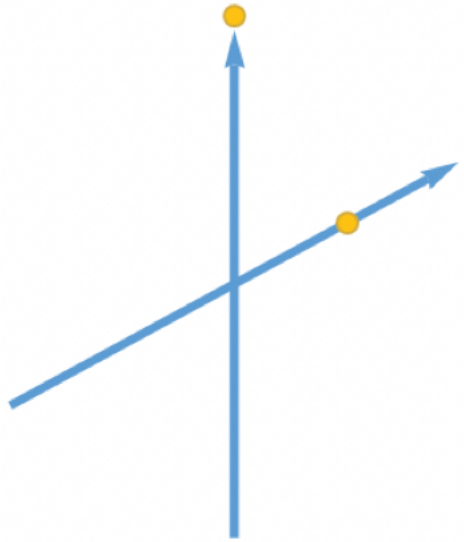
No!

The problem with the average conservation principle responsible for the quantum correlation function is that it holds *only on average* in different reference frames. Thus, it does not supply an explanation for outcomes on a trial-by-trial basis. This is quite unlike constraints we have in classical physics. For example, conservation of momentum holds on a trial-by-trial basis whenever the sum of the forces equals zero, and a light ray always takes the path of least time (Fermat's principle) because of refraction at the interface per Snell's law. Those constraints hold on average because they hold for each and every trial. In other words, constraints are typically explained dynamically and hold on a trial-by-trial basis. Therefore, we seek something other than a dynamical/causal mechanism to account for this "average-only" conservation principle.

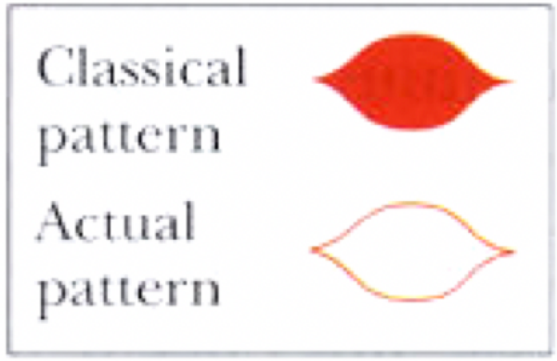
Conservation per No Preferred Reference Frame

Why NPRF?

To motivate NPRF for the Bell spin states, consider the empirical facts. First, Bob and Alice both measure $\pm 1\left(\frac{\hbar}{2}\right)$ for all SG magnet orientations, i.e., in all reference frames. In order to satisfy conservation of spin angular momentum for any given trial when Alice and Bob are making different measurements, i.e., when they are in different reference frames, it would be necessary for Bob or Alice to measure some fraction, $\pm \cos\theta$, as I explained above. For example, if Alice measured +1 at $\alpha = 0$ for an S = 1 state and Bob made his measurement at $\beta = 60^o$ (both in the plane of symmetry), then Bob's outcome would need to be $\frac{1}{2}$. In that case, we would know that Alice measured the "true" angular momentum of her particle while Bob only measured a component of the "true" angular momentum for his particle. Thus, Alice's SG magnet orientation would definitely constitute a "preferred reference frame."



But, this is precisely what does *not* happen. Alice and Bob both always measure $\pm 1\left(\frac{\hbar}{2}\right)$, no fractions, in accord with NPRF. And, this fact alone distinguishes the quantum joint distribution from the classical joint distribution. Therefore, the average-only conservation responsible for the correlation function for the Bell spin states leading to Facts 1 and 2 for the Mermin device is actually **conservation resulting from NPRF**.



This is not the only mystery in modern physics resulting from NPRF.

Mystery of Special Relativity from NPRF

In special relativity (SR), Alice is moving at velocity $\vec{V}_A$ relative to a light source and measures the speed of light from that source to be $c = \frac{1}{\sqrt{\epsilon_o \mu_o}}$. Bob is moving at velocity $\vec{V}_B$ relative to that same light source and measures the speed of light from that source to be *c*. Here "reference frame" refers to the relative motion of the observer and source which then defines a specific measurement of a specific quantity in the context of all its alternatives. NPRF in this context thus means all measurements produce the same outcome *c*. This fact leads to time dilation and length contraction, i.e., the mystery of SR.

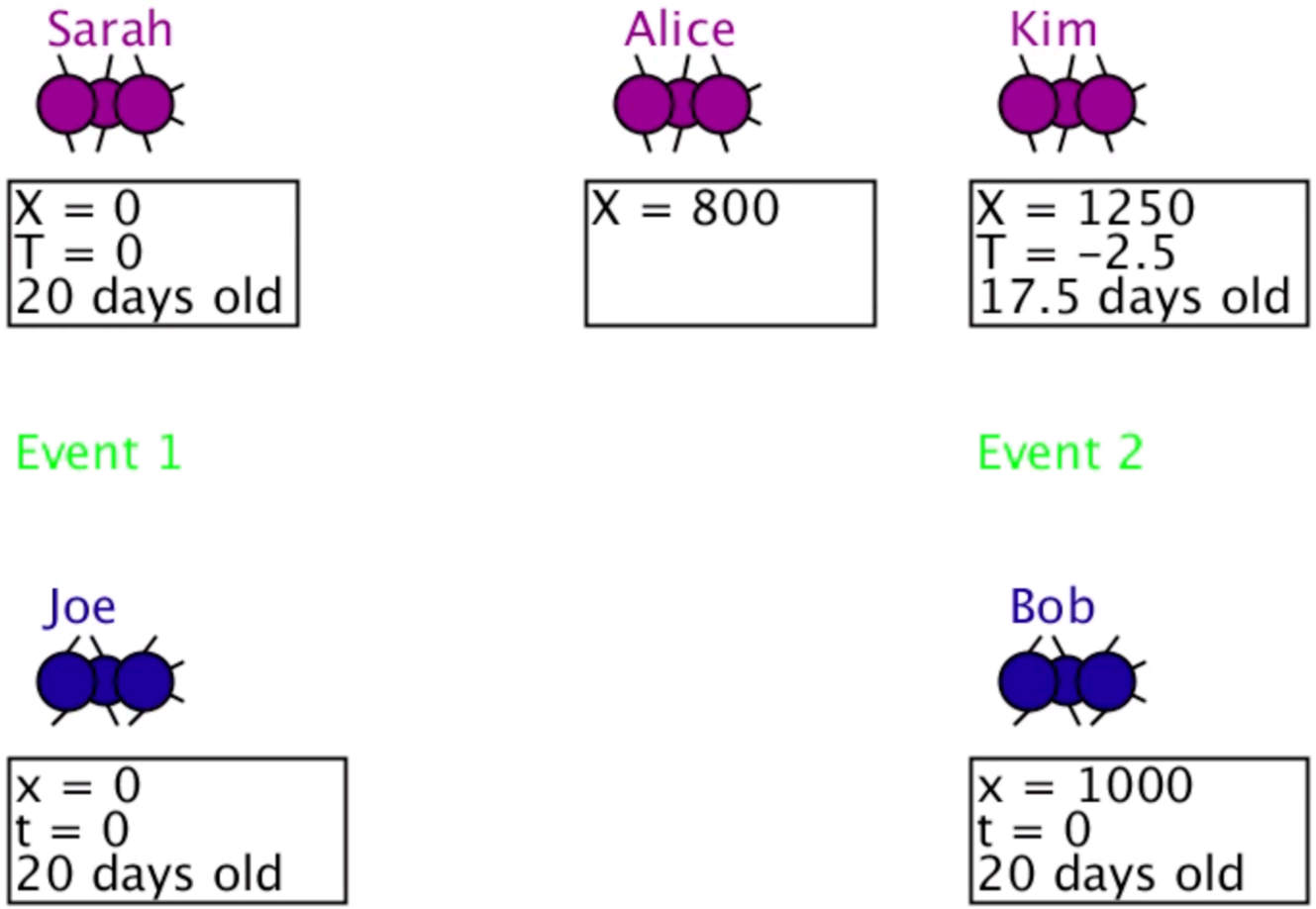
Relativity of Simultaneity

Event 1: 20 day old Joe and 20 day old Sarah meet

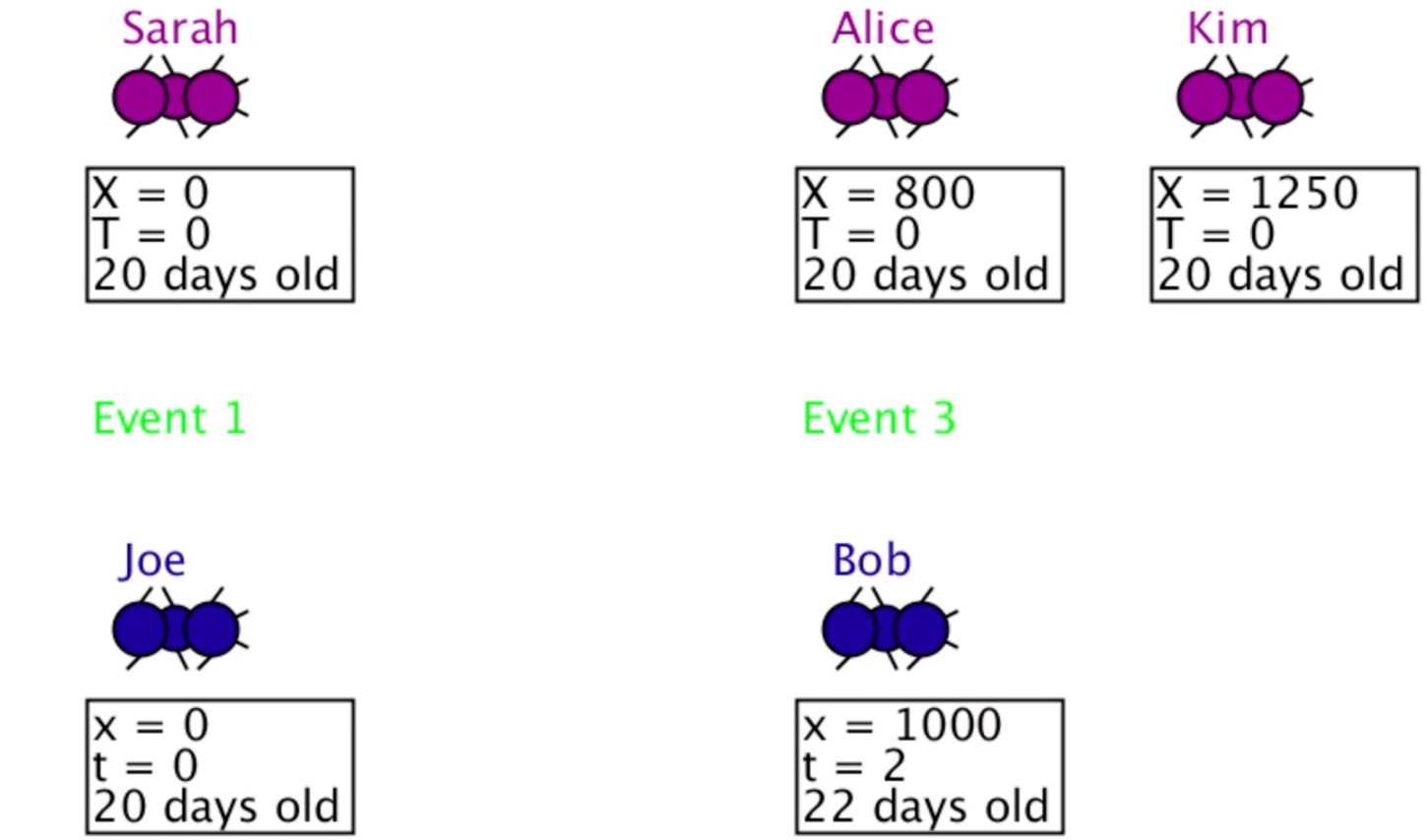
Event 2: 20 day old Bob and 17.5 day old Kim meet

Event 3: 22 day old Bob and 20 day old Alice meet

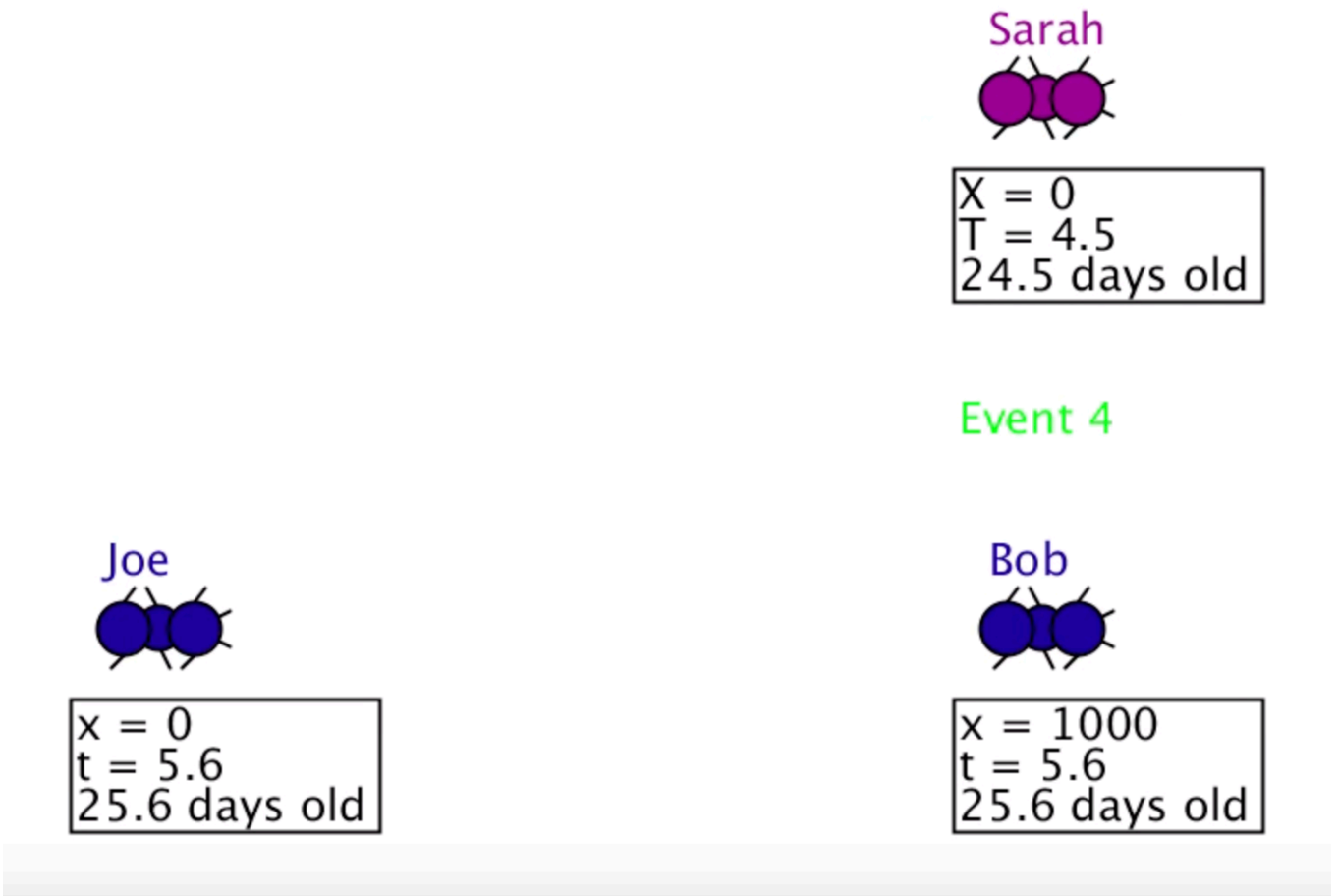
Event 4: 25.6 day old Bob and 24.5 day old Sarah meet



Boys say Events 1 and 2 are simultaneous, so the distance between Sarah and Kim is 1000km, not 1250km as measured by the girls (length contraction). [Note: Time differences are exaggerated for effect. These results obtain for 0.6*c* relative velocity.]



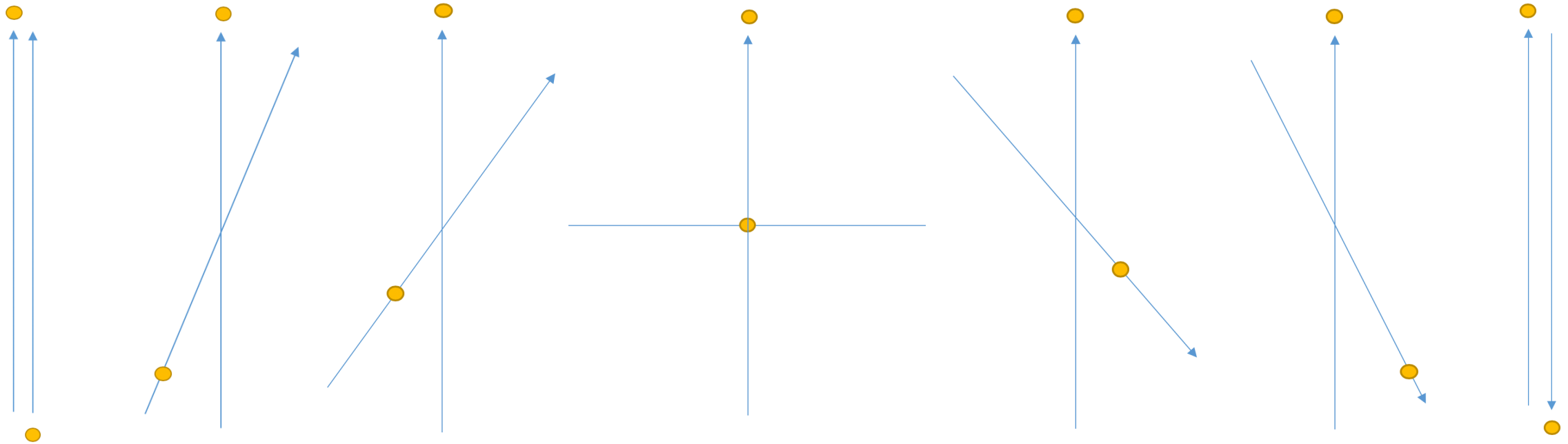
Girls say Events 1 and 3 are simultaneous, so the distance between Joe and Bob is 800km, not 1000km as measured by the boys (length contraction). And, Bob has aged only 2 days between Events 2 and 3 while the girls say they have aged 2.5 days, so the girls say that Bob's clock is running slow (time dilation).



Sarah has aged only 4.5 days between Events 1 and 4 while the boys say they have aged 5.6 days, so the boys say that Sarah's clock is running slow (time dilation).

All this disagreement (mystery) about whose clocks are slow and whose meter sticks are short happens because everyone measures the same speed of light *c,* regardless of their different velocities relative to the source, in accord with NPRF.

Average View for Spin Singlet State Entanglement



Alice's(Bob's) view of Bob(Alice). This disagreement about who needs to average their results happens because everyone always measures $\pm 1\left(\frac{\hbar}{2}\right)$, no fractions, regardless of their SG magnet orientations, in accord with NPRF.

Special Relativity	Quantum Mechanics
Empirical Fact: Alice and Bob both measure *c*, regardless of their relative motion	Empirical Fact: Alice and Bob both measure +1/-1 $\left(\frac{\hbar}{2}\right)$, regardless of their relative SG orientation
Alice(Bob) says of Bob(Alice): Time dilation and length contraction	Alice(Bob) says of Bob(Alice): Must average results
NPRF: Relativity of simultaneity	NPRF: Relativity of data partition
Violate NPRF: Posit empirically unverifiable ether constituting a preferred frame	Violate NPRF: Posit empirically unverifiable HV residing in a preferred frame

Because Alice and Bob both measure the same speed of light *c* regardless of their relative motion per NPRF, Alice(Bob) may claim that Bob's(Alice's) length and time measurements are erroneous and need to be corrected (length contraction and time dilation).

Likewise, because Alice and Bob both measure the same values for spin angular momentum $\pm 1 \left(\frac{\hbar}{2}\right)$ regardless of their relative SG magnet orientation per NPRF, Alice(Bob) may claim that Bob's(Alice's) individual ± 1 values are erroneous and need to be corrected (averaged).

In both cases, NPRF resolves the mystery it creates.

In SR, the apparently inconsistent results can be reconciled via the relativity of simultaneity. That is, Alice and Bob each partition spacetime per their own equivalence relations (per their own reference frames), so that equivalence classes are their own surfaces of simultaneity and these partitions are equally valid per NPRF.

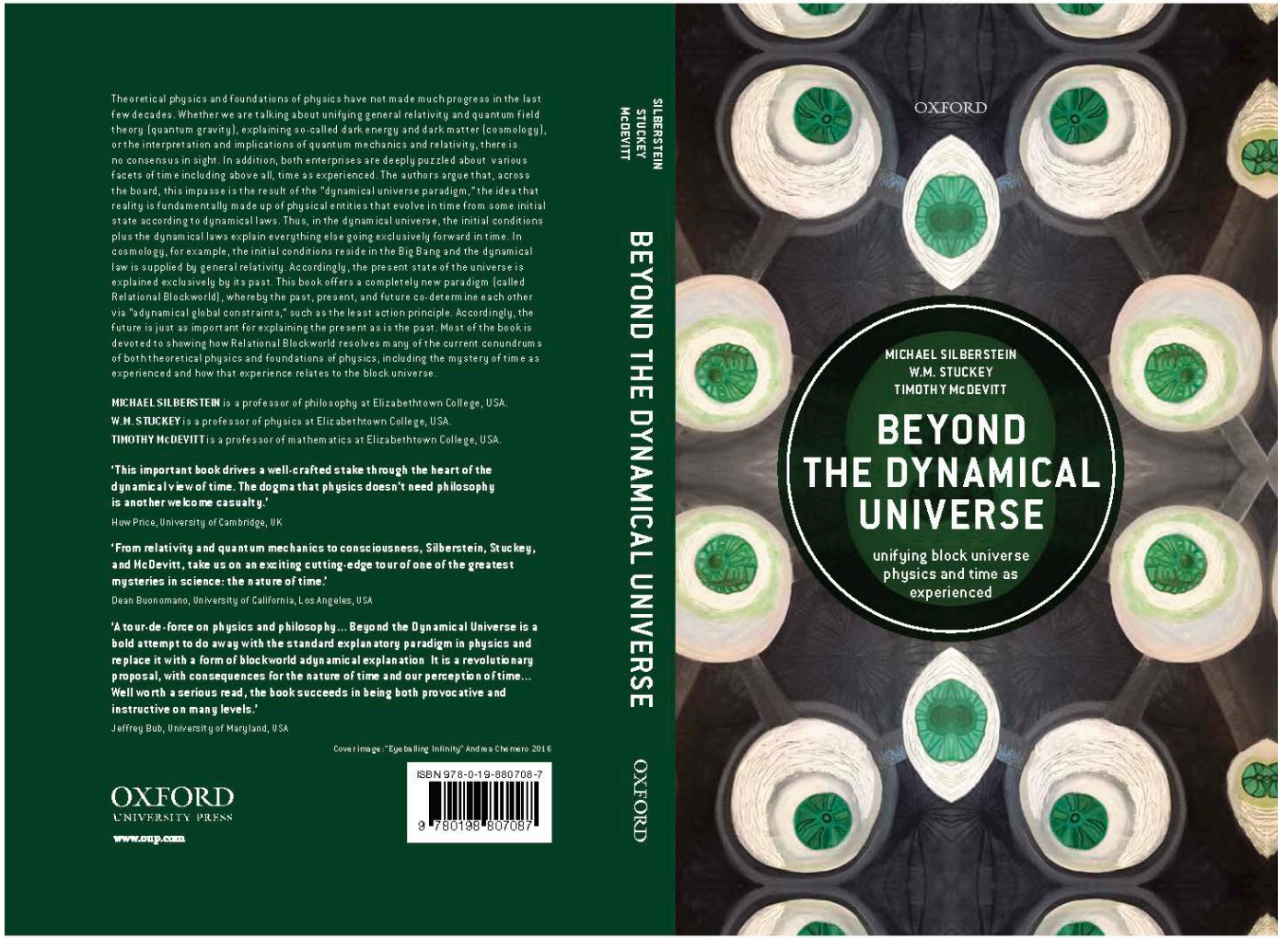
This is completely analogous to QM, where the apparently inconsistent results per the Bell spin states arising because of NPRF can be reconciled by NPRF via the “relativity of data partition.” That is, Alice and Bob each partition the data per their own equivalence relations (per their own reference frames), so that equivalence classes are their own +1 and -1 data events and these partitions are equally valid per NPRF.

Smolin recently wrote ("Einstein's Unfinished Revolution: The Search for What Lies Beyond the Quantum," 2019):

> I hope to convince you that the conceptual problems and raging disagreements that have bedeviled quantum mechanics since its inception are unsolved and unsolvable, for the simple reason that the theory is wrong. It is highly successful, but incomplete.

Of course, this is precisely the complaint leveled by Einstein, Podolsky, and Rosen in their famous 1935 paper, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" But, I have shown that QM is complete given that everyone has to measure the same values for the fundamental constants of Nature (*h* in this case), regardless of their reference frame. And, this same principle of "no preferred reference frame" (NPRF) is also responsible for the mysteries of length contraction and time dilation in SR because everyone has to measure the same value of *c*. Thus, we see that the mystery of entanglement does not indicate that QM is somehow incompatible with SR, as some believe. On the contrary, the mystery of entanglement is evidence that QM and SR are deeply coherent per NPRF.

Again, for an overview of adynamical, constraint-based explanation resolving puzzles, problems, and paradoxes throughout modern physics see:



Theoretical physics and foundations of physics have not made much progress in the last few decades. Whether we are talking about unifying general relativity and quantum field theory (quantum gravity), explaining so-called dark energy and dark matter (cosmology), or the interpretation and implications of quantum mechanics and relativity, there is no consensus in sight. In addition, both enterprises are deeply puzzled about various facets of time including above all, time as experienced. The authors argue that, across the board, this impasse is the result of the "dynamical universe paradigm," the idea that reality is fundamentally made up of physical entities that evolve in time from some initial state according to dynamical laws. Thus, in the dynamical universe, the initial conditions plus the dynamical laws explain everything else going exclusively forward in time. In cosmology, for example, the initial conditions reside in the Big Bang and the dynamical law is supplied by general relativity. Accordingly, the present state of the universe is explained exclusively by its past. This book offers a completely new paradigm (called Relational Blockworld), whereby the past, present, and future co-determine each other via "adynamical global constraints," such as the least action principle. Accordingly, the future is just as important for explaining the present as is the past. Most of the book is devoted to showing how Relational Blockworld resolves many of the current conundrums of both theoretical physics and foundations of physics, including the mystery of time as experienced and how that experience relates to the block universe.

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W.M. STUCKEY is a professor of physics at Elizabethtown College, USA.
TIMOTHY McDEVITT is a professor of mathematics at Elizabethtown College, USA.

'This important book drives a well-crafted stake through the heart of the dynamical view of time. The dogma that physics doesn't need philosophy is another welcome casualty.'
Huw Price, University of Cambridge, UK

'From relativity and quantum mechanics to consciousness, Silberstein, Stuckey, and McDevitt, take us on an exciting cutting-edge tour of one of the greatest mysteries in science: the nature of time.'
Dean Buonomano, University of California, Los Angeles, USA

'A tour-de-force on physics and philosophy... Beyond the Dynamical Universe is a bold attempt to do away with the standard explanatory paradigm in physics and replace it with a form of blockworld adynamical explanation. It is a revolutionary proposal, with consequences for the nature of time and our perception of time... Well worth a serious read, the book succeeds in being both provocative and instructive on many levels.'
Jeffrey Bub, University of Maryland, USA

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TIMOTHY McDEVITT

BEYOND THE DYNAMICAL UNIVERSE

unifying block universe physics and time as experienced

Thus, as a “physicist reader” of Mermin’s AJP paper, “Quantum Mysteries for Anybody,” my explanation for how the Mermin device works “in terms meaningful to a general reader struggling with the dilemma raised by the device” is:

Facts 1 and 2 for the Mermin device obtain because of conservation per no preferred reference frame.