New Pathways to Quantum Spring: Can Information About States Be Made More Democratic?

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Quantum theory curiously implies that preparers of states can know the complete initial specification of the state, but uninformed observers (UOs) are limited in what they can discover. UOs must currently use projective tests that typically destroy the original information. There is thus more to "it" than democratically available as "bit." Previous attempts to empower UOs include weak measurements and using repeated interactions between detector and one particle. A novel theoretical perspective and thought experiment are introduced to distinguish between supposedly equivalent mixtures of states. The original-spin hypothesis postulates that actual spin transfers from photon interactions remain based on the original expectation value, instead of the final apparent detection. The proposal itself uses mechanical spin transfer by statistical "runs" of same-type detections, as analyzed by the OSH, to expand what UOs can find out. It would not be practical, but stimulates theoretical insight. A supportive asymmetry claim about detection is currently testable.

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Introduction and overview

In this author’s view, being unable in principle to find out *everything* about the world’s contents implies that “bit” (information) is derivative and subsidiary to “it” (real objects.) Quantum limitations “on knowledge” are widely known, such as various uncertainty principles. However, the UP can be framed as an *intrinsic* property of an objectified wave function. Less well publicized is the basic asymmetry in possible knowledge for observers. Common sense suggests that a "real property" would be measurable by anyone, if knowable at all. Yet privileged access is a key feature (even if under-appreciated) of quantum theory. It is a foundation of quantum information science and cryptography. Observers who create a particle are able (at best) to know its complete wave function – the complete quantum specification of that particle. They might pass this knowledge on ... or not. We can refer to those with inside information as preparing or privileged observers (POs.) Observers with less privileged access must (typically) settle for tests granting probabilistic answers to crude binary guesses, such as the chance a photon will pass a polarizing filter at a given angle. These are uninformed/unprivileged observers, UOs.

This curious asymmetry also applies to ensembles of particles. For example, the PO knows that one randomized mixture of photons is differently comprised than another mixture. For example: one is a mix of horizontal and vertical (H and V) linear states, the other is a mix of R and L circular. Yet these two are "equivalent" because they have the same density matrix: $(|R\rangle \langle R| + |L\rangle \langle L|)/2 = (|H\rangle \langle H| + |V\rangle \langle V|)/2$, etc. A UO doesn’t know how (at least using “ordinary measurements”) to *find out* they are different, much less in what specific way. Those not subscribing to the “ignorance interpretation” will question whether *fully* unknown properties would even be valid in principle, but the asymmetry itself is empirically verifiable. A PO, knowing a photon was created with linear axis at say 20 degrees, can reliably demonstrate its passage through a corresponding filter. Yet UOs can only guess, and their attempt to find out destroys the original specification.

Pessoa [1] provides an excellent technical overview of the mixture problem and its meaning, including some unsuccessful early speculations about distinguishing such mixtures. He proposed a possible way, different from that here, to distinguish “different but equivalent” mixtures by using second-order coherence effects and some undoing of creating the mixture. It requires some additional knowledge of beam preparation.

Effectively then, “information" is tied to one's specific knowledge of how particles were created and their early interactions. Yet if information is fundamentally "real," intuition says it should ultimately be tied to universal and widely accessible "properties." This intuition is supported by a scientific/philosophical tradition of empiricism and verificationism, aside from their strict validity. How can "real" properties be so opaque to the less privileged? Here, we explore whether we can find more about individual and ensemble quantum states than thought possible. Some previous proposals are briefly reviewed. Also, thought experiments are introduced that might distinguish supposedly equivalent mixtures.

Mixtures are approached here in a new way. First, we examine the interactions of atypical portions ("runs") of sequences, rather than average mixture properties. Second, we advantage the mechanical properties of angular momentum, rather than just "filtering" *per se*. We analyze and predict based on a new conjecture about some types of quantum measurements: the original-spin hypothesis. Standard theory says that detection of an arbitrary particle “as” a given state causes the same cumulative consequences as a particle that had already been in that state (unitary linear evolution with collapse.) The OSH postulates instead, that photon interactions transfer spin (at least cumulatively) based on the original expectation value (average measured value) rather than final apparent detection type. That circular states probably retain their effective spin despite being “detected as” linear, is testable and would support the OSH.

Most of these techniques are sadly impractical; hence as "thought experiments" they challenge and stimulate theoretical study. Note that we have already shed some early suppositions of QM, such as that observing must "disturb" an object (disproved with interaction-free measurements.) These issues are important. If our world can be characterized in terms of "information," its basic character hangs in the balance. Is it a secretly-bitted class society favoring those who know the confidential ingredients of the cook's special sauce? Yet can properties that aren’t universally accessible represent physical “information, at least potentially? Or, do we live in a openly-bitted world instead where anyone can aspire to know what is "real" about an object – even a quantum object? Although the scope of “it” will still surpass that of “bit,” the gap would be narrowed.

Some previous attempts to democratize quantum information

The theory of "weak measurements" was an early attempt to expand access to quantum states (although without violating specific quantum rules.) Y. Aharonov *et al* proposed [2] to study quantum states with interactions that shifted the state of an interacting meter without disturbing the state. Later measurements can find amplified values for the state, revealing information about an ensemble that would otherwise not be available (such as larger displacements in a Stern-Gerlach device.) Related recent developments have been impressive, such as tracing the paths of photons [3] in the two-slit experiment (albeit not showing the path of any specific single photon.) From the abstract:

"A consequence of the quantum mechanical uncertainty principle is that one may not discuss the path or “trajectory” that a quantum particle takes ... Using weak measurements, however, it is possible to operationally define a set of trajectories for an ensemble of quantum particles."

Lundeen *et al* [4] published a report with the ambitious title, “Direct measurement of the quantum wavefunction." From the abstract:

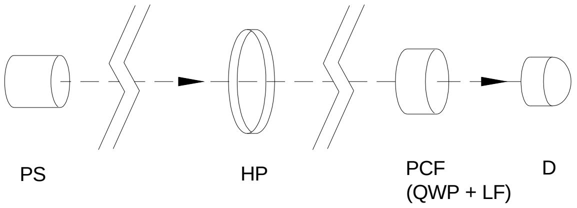
"Here we show that the wavefunction can be measured directly by the sequential measurement of two complementary variables of the system. The crux of our method is that the first measurement is performed in a gentle way through weak measurement so as not to invalidate the second."

This author recently proposed [5] a thought experiment to find details of the polarization state of an isolated single photon, going beyond the protocols and expectations of weak measurement. In this impractical but conceptually unique method, an arbitrarily polarized photon is repeatedly cycled through a measurable half-wave plate (including intervening corrections.) Such plates are “special.” Unlike filters, they do not collapse the state of a photon: they simply swap the magnitudes of $|R\rangle$ and $|L\rangle$ components by changing relative phase between linear components. Hence, through analogy with the passage of many photons, I proposed that the plate increments angular momentum in proportion to the relative R and L magnitudes of the original photon superposition. Surprisingly, successful application would distinguish circular from elliptical from linear (one degree of freedom.) This TE raises interesting questions about measurement and interaction, aside from whether implementation would actually provide an UO greater access than current theory allows.

Another set of proposals [6] can be tested by practical if somewhat difficult experiments. They attempt to falsify the proposition that decoherence effectively converts superpositions into mixtures, as some interpretations suppose or imply. If successful, they would recover phase information (or at least, demonstrate continuation *per se* of extended wave amplitudes) from states from which it was supposed lost due to destruction of coherence.

A novel proposal: how to distinguish supposedly "indistinguishable" mixtures

Must an UO accept inferior outsider status of not being able to tell the difference between supposedly equivalent mixtures? A new thought experiment (a similar version was outlined in a blog post [7], and elicited some relevant critiques) shows that perhaps the answer is actually and unexpectedly, "no." However, this TE would be difficult in practice because it requires waiting for very unlikely statistical runs. However, it being possible even in principle is of theoretical interest. Here we assume conventional limitations on characterization of single photons. Yet we find that if the OSH is true, application to detection runs might allow distinguishing between supposedly equivalent mixtures.



Mixture distinction apparatus
(schematic)
Note: component separations
may vary.

Figure 1.

The design of our TE is relatively simple (see Figure 1.) First, we have a source PS of independent sequential photons. PS can produce any single photon polarization on demand, as well as any specified pattern including "random." Alice knows what comes out but Bob curiously struggles to find out. PS is far away from the testing area, such that many photons can be examined before a signal could propagate back to it. Testing works as follows: photons first encounter a freely-rotatable half-wave plate HP. The angular momentum of HP and its change can thereby be measured. However, HP (limited by the uncertainty relation for angle and spin) can only show accumulation of many photon passes.

HP is followed by PCF, a common compound device regarded and used as a circular polarization filter. This construction uses a facing quarter-wave plate QP, followed by an attached linear filter LF. The axis of LF is held diagonal to the optical axes of QP. Pure circular states are transformed by QP into respectively orthogonal linear states. If PCF is set to detect L, then LF passes light transformed from L entry but absorbs light transformed from R entry. However, the output of this type of "circular filter" is a linear state! PCF is a pseudofilter. Importantly, its spin is measurable (orientation is irrelevant to detecting circular states.) Finally, behind PCF we have a simple photon detector D.

First, consider Mixture I: the response of the system to subsets of a randomized sequence of R and L photons. From time to time, "runs" of type RRRRR ... will naturally occur. The chance of such a run starting "now" is of course 1:2^n. Each time an R photon enters: first it transits HP, which flips the photon to L and imparts $2\hbar$ to the plate. QP then converts the L state into a (relatively) diagonal linear state that passes LF – exiting as that linear state. Hence the angular momentum of PCF changes by $-\hbar$. D records a click. If n is sufficient, we can measure the changes in HP and PCF. Bob needs luck, starting to measure values just before a run starts and then checking after. (However, success does not require all these photons to be the same. We only need enough unequal proportion for a discernible change.)

Furthermore, runs of type LLLLL ... will also occur. Each time, HP flips the photon to R, incrementing $-2\hbar$ to the plate. QP converts R into a diagonal linear state that LF absorbs. Hence the angular momentum of PCF changes by $\hbar$. D does not record a click, but we know the pre-planned intervals. In both cases, we expect AM to be conserved under many such interactions.

Note that if we deliberately supply n sequential photons of same type, the physical outcome should be the same. Hence the response does not depend on highly improbable events. The serial effects on angular momentum transfer are verifiable, and simply require refinement of the Beth experiment [8].

The various basic effects are shown in Table 1. It tabulates devices, mixture types, run types, cumulative changes in angular momentum, and detector counts; as predicted by standard quantum theory versus OSH. We demand *final* net conservation of spin for all predictions. Quote marks indicate either detections “as” – distinct from “actual” type – or questionable values. Special actions, such as pre-measurement of PS, are not shown. We can be reasonably sure of results for Mixture I: SQT and OSH agree. The results for Mixture II are debatable. Simple SQT does not allow distinguishing Mixture II from Mixture I. The proposed alternative results from OSH would allow distinguishing between the two mixtures. In practice, we don’t really need a pure run to yield measurable results. Also, variability and intrinsic uncertainty could give apparent spin results in OSH, but distinctly less than from SQT.

Device:	Run type (below)	PS	(presumed of photons, net)	HP	PCF	D (count)
Mixture I (R,L)						
(ΔS, after type) (SQT, OSH)	R	$-n\hbar$	$n\hbar$	$2n\hbar$	$-n\hbar$	n
	L	$n\hbar$	$-n\hbar$	$-2n\hbar$	$n\hbar$	0
Mixture II (H,V)						
SQT	“R”	$-n\hbar$	“0”	$2n\hbar$	$-n\hbar$	n
SQT	“L”	$n\hbar$	“0”	$-2n\hbar$	$n\hbar$	0
OSH	“R”	0	0	0	0	n
OSH	“L”	0	0	0	0	0

Table 1: Comparison of various predictions under SQT and OSH

Now, let's compare Mixture II: what happens if PS sends a stream of random H and V photons? Can Bob find the difference? Each H or V photon is (*i.e.*, can be considered as) an equal superposition of R and L states (see Technical Appendix as needed.) Each time either type enters: first it transits HP, which preserves both circular components but may change the angle of polarization. In advance of a “detection” elsewhere, that should not change the expectation value of the angular momentum of HP. The still-linear state will encounter QP at various relative angles, with various outputs along the range from linear to circular. In any case, the chance the intermediate output will exit LF, prompting a supposed “detection as L circular,” is 50%.

Yet consider that from time to time, there will be runs of apparent R and L detections (for a completely different reason than from Mixture I.) The crucial challenge raised here is: how does that affect the angular momentum of the components? Conventional quantum theory implies that absorption of a linear state inside PCF is detection "as" an L photon, and passage out (even of another linear photon) is detection "as" an R photon. If so, we expect PCF to increment by $\hbar$ if end-stage "R," and $-\hbar$ if "L." By consistency with unitary linear evolution now being "collapsed," the rest of the causal chain should follow suit. We expect the spin of HP and even PS to also increment accordingly, as they do after encountering or emitting real (*i.e*, original) circular states. They are revised by entanglement even at a distance!

Changes of only a few $\hbar$ could “hide” inside angle/spin uncertainty, and we could be complacent things will “work out” if we consider only average outcomes. But now, the large anomalous run size n can cause observable changes in macroscopic spin. Quantum theory, naively applied, makes the paradoxical claim that our components will *act like* they encountered a run of actual R or L photons. The zero net spin imagined originally in the sequence itself, is now irrelevant. (Again, this is not the same as entanglement requiring correlated measurements of two particles. Also, this is not "revision" of an already-observable quantity. It’s part of the consistency of what we are finally able to observe. Clearly, this predicted outcome would prevent Bob from distinguishing the two mixtures. Is it how nature behaves?

Perhaps it isn’t. There are enough problems and paradoxes with the conventional view to prompt reconsideration. For example, we can monitor PS first. The intuition that monitoring disallows adequate specification of photon type, is false. "Freely rotatable" doesn't mean having to swing in a wide arc, it means "not rigid." The requirement is only a certain inverse floor between knowing the angle versus uncertainty of angular momentum. We can orient PS within a few degrees and still detect changes of hundreds of $\hbar$. Say Alice monitors emission of many linear photons, and finds negligible change (as expected) in PS. Are those photons now "forbidden" from creating a detectable run of "R detections" later -- not even with a chance of $1{:}2^n$? Standard theory would seem to enforce this prohibition. Yet each emitted photon, as a superposition of R and L, should supposedly retain the chance to be detected as "R" or "L" – with all that implies about statistical variations such as runs! Would these photons "coordinate" with each other to require a consistently even R:L balance – as if coins could collaborate to disallow long runs of heads or tails? (We can ask similar questions about pre-monitoring of HP.) Now what should we think? Clearly, deeper treatment of statistics raises new questions.

We raise another challenge by substituting a fixed QP with horizontal/vertical optical axes, followed by a separate, fixed diagonal linear filter LF (or separating prism instead.) Now, we can't measure angular momentum of these elements. The passage of a linear photon through QP still involves superposition of R and L passage. Yet a "linear photon" arrives at the now-separate LF in the same condition (H or V) it arrived. It has the same, "meaningless" 50/50 chance per se of passing a diagonal filter as would any other entering H or V photon. This latter interaction by itself doesn’t seem to have any particular relation to circular bases. This combination of elements is just coincidentally a "trick" (an indirect, deductive process) for finding actual circular photons, should they arrive – or is it? It is now even harder to conceptually imagine why PS and HP should react as if handling real R or L photons, during an indirect apparent "detection" run.

We find another clue from the likely asymmetry of detection as circular versus detection as linear. For example, direct a stream of R photons at a two-channel linear polarization detector D_L. We can measure the angle and angular momentum of D_L to desired accuracy. We will find each R photon "detected as" either, say, H or V. Neither linear state has net spin, so a run isn't even relevant. However, few expect D_L (or the emitter) to not exhibit the expected changes in angular momentum from absorbing genuine "R" photons. Surely, the system would violate conservation if it acted like it received an actual sequence of H and V photons. This experiment can and should be done, likely yielding the asymmetrical result that circular photons transfer spin, regardless. *Yet why should linear detected "as circular" prompt change in angular momentum, yet circular detected "as linear" continue to exert the effects of circular?*

Consideration of elliptical polarization refines the point. Would apparent runs of elliptical *detections* cause intermediate incrementation/revision of spin throughout the system? Is this spin subject to further collapse upon later measurements? There should not be a discontinuity with the above expectations about linear detections. Use of elliptical *states* $a|R\rangle + \beta|L\rangle$ raises the challenge of whether apparent runs of RRRRR... would prompt upward revision of intermediate levels of angular momentum.

Again, all this seems awkward, especially since $|R\rangle$ and $|L\rangle$ states seem more "fundamental" as expressions of spin. Can we imagine an ugly rule that allows "upward revision" of spin (as from linear to circular) in the system, but not "downward" (circular to linear or elliptical) revision? Perhaps, given all this, conventional "detection" is misleading. Wouldn't it be simpler if there just wasn't any such revision at all? Perhaps the cumulative *mechanical effects* of photons are based on their original spin expectation value, regardless of what they are apparently detected as later. This is the original-spin hypothesis. If the OSH is valid, UOs will be able to distinguish the two types of mixtures.

We find support for the special status of angular momentum in the following challenge to simple unitary linear evolution. Consider that passage of state $|H\rangle$ or $|V\rangle$ through a HWP should be a superposition, in proper phase, of the effects of separate passage of $|R\rangle$ and $|L\rangle$. This principle does correctly apply to the photon output states. Also, with either $|H\rangle$ or $|V\rangle$, the spin of the plate becomes a superposition of opposite extra spin vectors. The net expectation value $\langle S\rangle$ remains unchanged, as we expect from summing the effects from $|R\rangle$ and $|L\rangle$.

However, the $|R\rangle$ state is also a superposition of $|H\rangle$ and $|V\rangle$. Photon output is again what we expect from superposed linear evolution (the summed in-phase $|R\rangle$ and $|L\rangle$ interfere, so that only $|L\rangle$ exits.) Yet the *plate's* $2\hbar$ increment of spin cannot be reasonably represented by summing the effects *on the plate* of passage of $|H\rangle$ and $|V\rangle$. The spin vectors in the plate do not have phases - they are (?) simple vectors of angular momentum. Hence, net quantities are simply additive. Summing the (as yet uncollapsed) effects of $|H\rangle$ and $|V\rangle$ passage, simply yields superposed rotational states. If the separate effects of $|H\rangle$ and $|V\rangle$ on the plate are $|H'\rangle$ and $|V'\rangle$, the effects of the photon state $a|H\rangle + \beta|V\rangle$ *do not* lead to *plate* state $a|H'\rangle + \beta|V'\rangle$! The plate does not manifest full unitary evolution, at least straightforwardly.

Conclusion

Most of the proposals here are impractical. For example, we may never be able to actually test improbable detection runs for spin in the manner described. However, we at least have grounds to suspect that current quantum theory exaggerates the exclusivity of quantum information. We found it is not enough to consider mixtures (or sequences) in simple, averaged terms – we must consider special properties of statistically unusual special series ("runs.")

Also, tangible angular momentum is clearly not incidental to what we can know about quantum objects. It is not a simple correlate of filtering results. Spin does seem to be both special and complicated in QM – note for example its perplexities in the Majorana description and in Bohmian mechanics. Spin may be the basis for an asymmetry in the consequences of measurement, including the workings of unitary evolution. Perhaps I am mistaken - but we should at least reexamine the presumption that statistical coincidences that simulate runs of circular photons, will produce *all* the same results as real such runs. If the original-spin hypothesis seems attractive, quantum theory will be on a route to possible revision.

Note that even if we can expand the domain of accessible information – *lessen* the dominance of “it” over “bit – there is still plenty we probably can't know. We won't be able to map the distribution of a photon's wavefunction in space, even if it turns out we can find more complete information about its polarization state. We still can't know the initial state of any one entangled particle, because strong correlations are incompatible with specified elements of "reality" for that particle. We still won't really understand wavefunction collapse, despite various controversial attempts to explain it. Further study of these issues is needed and welcomed – for the sake of foundational understanding, and because access to information has such practical importance.

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Technical Appendix

A review of relevant aspects of quantum measurement, concentrated on photon polarization, is helpful. Penrose [9] provides a good accessible overview of these and related topics. A photon can be considered either as a pure basis state, or as a superposition of such basis states. Since orthogonal states form a complete set, we only need two states for a complete characterization – but there are many pairs to choose from. In discussions of spin, the appropriate bases are right-hand and left-hand states of circular polarization. (Here, "right" means angular momentum is parallel to photon propagation.) The orthogonal states comprise mutually exclusive chances of ideal detection. Probability of detection is proportional to amplitude squared. Using complex notation for phase angle, a photon could for example be $0.8|R\rangle + 0.6i|L\rangle$. This photon corresponds to elliptical polarization, and has a 64% probability of being detected "as R" and 36% of detection "as L."

Since circular states carry spin, composite states represent intermediate expectation values (the average from many measurements) of spin. For example, the state $0.8|R\rangle - 0.6|L\rangle$ has the spin expectation value of $(0.64 - 0.36)\hbar = 0.28\hbar$. It is convenient to refer to the coefficient $a^2 - b^2$ as the circularity C.

We could instead make our bases from horizontal linear polarization H (relative to some lab standard) and vertical polarization V, following the same protocols and with corresponding implications as before. The basis states can be decomposed as "made of each other." Hence, in terms of starting phase: $|V\rangle = 1/\sqrt{2}\,(|R\rangle - |L\rangle)$. States $|H\rangle$ and $|V\rangle$ each have 50/50 chance of detection as either R or L, and vice versa.

When a state passes a detector test (is "detected as") for a given state such as "R," almost all previous information about the state is destroyed. Whatever it was before, we now only know (ideally) that it could not have been a pure $|L\rangle$ state. If the photon survives testing (such as passing a filter), it ideally is now literally in that state (projection postulate.) It will certainly be detected as "R" in the future. (This is an oversimplification, since some "filters" work in a more complex way, for example releasing linear light in response to passing an R test. However, prior information was still destroyed.) According to most interpretations of collapse and unitary evolution, the state of everything else the photon has interacted with becomes consistent with the apparent new-found identity. However, it is already near-certain that detection of circular states “as linear” does not eliminate the transfer of the original spin.

The angle-spin uncertainty principle: being able to know about angular momentum does not require a rigid rotor. Instead, there is a trade-off between knowledge of angular momentum and knowledge (or fixing) of rotor angle. This relation is given as $\Delta S \Delta\theta \geq \hbar/2$. Hence, we can still know *e.g.* that a source emits essentially V states while monitoring its AM to within hundreds of $\hbar$.