

# Quantum Mechanics, by Itself, Implies Perception of a Classical World.

## Abstract

Quantum mechanics, although highly successful, has two peculiarities. First, in many situations it gives more than one potential version of reality. And second, the wave function for a macroscopic object such as a baseball can be spread out over a macroscopic distance. In the first, quantum mechanics seems to imply that the observer will perceive more than one version of reality and in the second it seems to imply we should see spread-out, blurred objects instead of sharply delineated baseballs. But neither implication is true. Quantum mechanics, by itself, implies more than one version of reality will never be reportably perceived, and it implies the perceived position of a baseball will always be sharply defined. Further, two observers will never disagree on what they perceive. Thus quantum mechanics, by itself, with no assumption of particles or collapse, always leads to the perception of a classical-appearing universe.

## Introduction.

Quantum mechanics is a highly successful theory of the physical universe but it has two peculiarities: first, its wave functions often contain several simultaneously existing versions of reality; and second, in the case of a macroscopic object such as a baseball, it can give a continuous infinity of possible positions spread out over, perhaps, a meter. The problem is how to reconcile a multi-version, spread-out wave function with the fact that we perceive only one, classical version of reality, sharply in focus, with a definite position.

There are three potential ways to solve this problem. The first, for which there is currently no evidence [1,2], is to suppose there exist particles (or hidden variables) that constitute a unique physical reality underlying quantum mechanics. The second, for which there is also no evidence [2,3], is to suppose the wave function collapses down to just one version of reality. The third possibility, the option advocated here, is to argue that quantum mechanics, by itself, without invoking either collapse or the existence of particles, leads to the *perception* of a classical single-version world of localized objects [2].

Zurek [4,5], among others (including Everett [6]), has also argued for the third option, but his argument is unnecessarily complicated, using the environment, einselection, decoherence and ideas from information theory. Our

treatment is much simpler and more straightforward. It shows directly, from the testimony of the observers themselves, that quantum mechanics implies a non-classical result will never be perceived.

We first use a Stern-Gerlach experiment, with no assumption of collapse or hidden variables, to show that more than one version of reality cannot be *reportably* perceived. Then we show that the smeared-out, non-localized wave function of a baseball still leads to the *perception* of a localized baseball with sharp outlines and features. And in both the Stern-Gerlach and baseball cases, two observers never disagree on what is perceived. Thus quantum mechanics, by itself, never leads to non-classical perceptions.

### The Stern-Gerlach Experiment.

We do a Stern-Gerlach (S-G) experiment on a spin  $\frac{1}{2}$  particle. The system consists of the particle, with states + and -; two detectors, one on each path; photons that are reflected from the readings on the detectors to the eyes of the observer; and the observer, with an emphasis on the neural firing pattern of the observer's brain. The state vector at time  $t_0$ , before the particle goes through the S-G magnet, is

$$\begin{aligned}
 |\Psi(t_0)\rangle = & (a(+) |+\rangle + a(-) |-\rangle) \\
 & |D+,N\rangle |D-,N\rangle |\text{photons transmit NN}\rangle \\
 & |\text{obs neural pattern corresponds to NN; CL}\rangle \equiv \\
 & a(+) |1, t_0\rangle + a(-) |2, t_0\rangle, \\
 & |a(+)|^2 + |a(-)|^2 = 1
 \end{aligned} \tag{1}$$

where Y indicates yes, detection, N no detection, the  $a$ 's are numerical coefficients, and where we have asked the observer to write CL if she sees a classical version of the world and NON-CL if she sees anything else ( a double exposure or whatever). Several assumptions went into the form of this state.

- (1) We assume the Schrödinger equation for the constituent particles leads to stable macroscopic objects such as detectors and observers.
- (2) We assume the c.m. wave functions of the S-G apparatus, including the detectors, are localized so they have sharp outlines and details. (Spread-out wave functions will be considered below.)
- (3) We assume the quantum mechanical time evolution leads to the reflection of ambient photons that travel to the observer, with the reflected pattern depending on the readings of the detector dials.
- (4) We assume the quantum mechanical time evolution implies the photons activate the visual system with the activation leading to neural firing patterns (for Y, N and so on) which can be identified by a match to memory.
- (5) And we assume the observer perceives nothing in this single-version, non-spread-out-wave function scenario which is non-classical, and so she writes CL.

There is nothing particularly startling or radical in these assumptions, but they need to be stated.

We first consider the S-G experiment in the case where  $a(+)=1$ ,  $a(-)=0$  so there is only one version of reality. The resulting state at the end of the experiment, using the five assumptions, is

$$\begin{aligned} U(t,t_0) |1,t_0\rangle = & \\ |+\rangle|D+,Y\rangle|D-,N\rangle|photons\ transmit\ YN\rangle & \\ |obs\ neural\ pattern\ corresponds\ to\ YN; CL\rangle & \end{aligned} \quad (2)$$

where  $U(t,t_0)$  is the time evolution operator, and where

(6) We assume quantum mechanics implies the detectors work as expected, responding with a Y if a particle wave function goes through it and remaining at N if not.

Similarly

$$\begin{aligned} U(t,t_0) |2,t_0\rangle = & \\ |-\rangle|D+,N\rangle|D-,Y\rangle|photons\ transmit\ NY\rangle & \\ |obs\ neural\ pattern\ corresponds\ to\ NY; CL\rangle & \end{aligned} \quad (3)$$

Now we consider the time evolution of the full state, with both  $a(+)$  and  $a(-)$  different from zero. Using the linearity of  $U(t,t_0)$  and Eqs. (2) and (3), we arrive at

$$\begin{aligned} |\Psi(t)\rangle = & U(t,t_0) |\Psi(t_0)\rangle = a(+)|1,t_0\rangle + a(-)|2,t_0\rangle = \\ a(+)|+\rangle|D+,Y\rangle|D-,N\rangle|photons\ transmit\ YN\rangle & \\ |obs\ neural\ pattern\ corresponds\ to\ YN; CL\rangle + & \\ a(-)|-\rangle|D+,N\rangle|D-,Y\rangle|photons\ transmit\ NY\rangle & \\ |obs\ neural\ pattern\ corresponds\ to\ NY; CL\rangle \equiv & \\ a(+)|1,YN; CL\rangle_{full} + a(-)|2,NY; CL\rangle_{full} & \end{aligned} \quad (4)$$

Note that in a linear theory, the presence or absence of state  $|2\rangle$  does not affect the time evolution of state  $|1\rangle$ . Note also that the concept of “the” detector or “the” observer no longer exists; instead there are two *versions* of the observer and each detector. So if we define “objective” as “single-version,” there is no objective reality in quantum mechanics. Nevertheless, *each version* of the observer perceives, according to her own testimony, a classical world.

We can carry this analysis one step further. Suppose there are two observers instead of one and suppose the observers are asked to compare their perceptions. Then the result, according to quantum mechanics, is

$$\begin{aligned}
|\Psi(t)\rangle = & \\
a(+)|+\rangle|D+,Y\rangle|D-,N\rangle|\text{photons transmit YN}\rangle & \\
& |\text{obs}_1 \text{ neural pattern corresponds to YN; CL, agree on YN}\rangle \\
& |\text{obs}_2 \text{ neural pattern corresponds to YN; CL, agree on YN}\rangle + \quad (5) \\
a(-)|-\rangle|D+,N\rangle|D-,Y\rangle|\text{photons transmit NY}\rangle & \\
& |\text{obs}_1 \text{ neural pattern corresponds to NY; CL, agree on NY}\rangle \\
& |\text{obs}_2 \text{ neural pattern corresponds to NY; CL, agree on NY}\rangle
\end{aligned}$$

where

(7) We assume the equations of quantum mechanics imply that versions of the observer on the same branch of the wave function can communicate. Non-communication between versions on different branches follows from  $\langle \text{obs}_j; \text{YN} | U(t, t_0) | \text{obs}_j; \text{NY} \rangle = 0$ . (No reasonable time evolution can carry a neural state corresponding to perception of NY into one corresponding to YN.)

Thus, because NON-CL is never written, and because communicating versions of the observers agree, we conclude that quantum mechanics, by itself, implies all perceptions are classical.

### The general problem.

The same reasoning and conclusions hold if there are several possible outcomes, each corresponding to its own readout on the detector and each readout leading to its own neural firing pattern in the brain of the observer. There will be several versions of the observer and each will perceive a classical, single-output result.

$$\begin{aligned}
|\Psi(t)\rangle = \sum a(i)|i\rangle |\text{detectors read results corresponding to } i\rangle & \quad (6) \\
|\text{obs neural pattern corresponds to readout } i; \text{ CL}\rangle &
\end{aligned}$$

As an example, in a scattering or double-slit experiment with a spread-out wave function, where the detectors are grains of film, each version of the observer will perceive one and only one grain of film exposed. No non-classical result, such as seeing more than one grain exposed, will ever be (reportably) perceived.

### The preferred basis problem.

The two observer states in Eq. (4),  $|\text{obs} \dots \text{YN}; \text{CL}\rangle$  and  $|\text{obs} \dots \text{NY}; \text{CL}\rangle$ , are *forced* by the magnet-particle, particle-detector, detector-photon and photon-eye-nervous system interactions; they do not occur in Eq. (4) because a “preferred” basis was chosen. Nevertheless, because in general in quantum mechanics it is assumed to be permissible to use any basis, it is conceivable that the states

$$a|\text{obs}\dots\text{YN}; \text{CL}\rangle + b|\text{obs}\dots\text{NY}; \text{CL}\rangle \text{ and} \quad (7-1)$$

$$c|\text{obs}\dots\text{NY}; \text{CL}\rangle + d|\text{obs}\dots\text{YN}; \text{CL}\rangle \quad (7-2)$$

$$a^2 + |b|^2 = |c|^2 + |d|^2 = 1, \quad a\bar{c} + b\bar{d} = 0$$

are the ones that correspond to the possible states of “the” observer. But even if we use these states, nothing other than classical perceptions are reported (only CL is written; NON-CL is never written).

It is important to note that these states are deceptive. The two versions of the observer,  $|\text{obs}\dots\text{YN}; \text{CL}\rangle$  and  $|\text{obs}\dots\text{NY}; \text{CL}\rangle$ , with macroscopically different wave functions, cannot communicate or interact in any way so they correspond to two totally disconnected versions of the brain. (They are in different regions of Hilbert space.) One version can have no knowledge of the existence of the other version or what it perceives. Thus because the two state vectors in Eq. (7-1) refer to two non-communicating versions of the brain, the version of the observer in Eq. (7-1) (or (7-2)) could never *report* any non-classical perception (perception of more than one version), as is indicated by the absence of the observer writing NON-CL.

#### Appropriate bases for entangled states.

Because we are dealing with an entangled state, we need to be more precise in our choice of basis vectors than we were in Eq. (7). The definition of a basis is that any state of the system can be written as a linear combination of the basis vectors. Now our system consists of several subsystems—the particle, two detectors, photons and the observer—so any basis vector for the system must be a direct product of vectors from each of the subsystems. This disqualifies (7-1) and (7-2) as basis vectors for the system because they include only vectors from the observer sub-system. Further we know from Eq. (4) that any state of this entangled system can be written as a linear combination of the two vectors  $|1, \text{YN}; \text{CL}\rangle_{\text{full}}$  and  $|2, \text{NY}; \text{CL}\rangle_{\text{full}}$ . Thus, rather than the basis of Eq. (7), the basis for the entangled system consists of the two vectors  $|1, \text{YN}; \text{CL}\rangle_{\text{full}}$  and  $|2, \text{NY}; \text{CL}\rangle_{\text{full}}$  or any linear combination of them. That is (if we also include a second observer), the allowed bases are

$$\begin{aligned} a|+\rangle|D+, Y\rangle|D-, N\rangle|\text{photons transmit YN}\rangle \\ & |\text{obs}_1 \text{ neural pattern corresponds to YN}; \text{CL, agree on YN}\rangle \\ & |\text{obs}_2 \text{ neural pattern corresponds to YN}; \text{CL, agree on YN}\rangle + \quad (8-1) \\ b|-\rangle|D+, N\rangle|D-, Y\rangle|\text{photons transmit NY}\rangle \\ & |\text{obs}_1 \text{ neural pattern corresponds to NY}; \text{CL, agree on NY}\rangle \\ & |\text{obs}_2 \text{ neural pattern corresponds to NY}; \text{CL, agree on NY}\rangle \end{aligned}$$

$$\begin{aligned}
& c|+\rangle|D+,Y\rangle|D-,N\rangle|\text{photons transmit } YN\rangle \\
& \quad |\text{obs}_1 \text{ neural pattern corresponds to } YN; \text{ CL, agree on } YN\rangle \\
& \quad |\text{obs}_2 \text{ neural pattern corresponds to } YN; \text{ CL, agree on } YN\rangle + \quad (8-2) \\
& d|-\rangle|D+,N\rangle|D-,Y\rangle|\text{photons transmit } NY\rangle \\
& \quad |\text{obs}_1 \text{ neural pattern corresponds to } NY; \text{ CL, agree on } NY\rangle \\
& \quad |\text{obs}_2 \text{ neural pattern corresponds to } NY; \text{ CL, agree on } NY\rangle
\end{aligned}$$

$$|a|^2+|b|^2=|c|^2+|d|^2=1, a\bar{c}+b\bar{d}=0$$

We still have combinations of state vectors in which the observers perceive different results. But, as in Eq. (7), the two parts of the combinations are in non-interacting “universes” so that one part of the combination cannot affect what the other part perceives and reports. That is, in the states of (8-1) and (8-2), only CL and “agree” are written so, by the testimony of the observers themselves, nothing non-classical is ever perceived. (As a reminder, the CL and “agree” came from an analysis of the *single-version* states  $a(+)=1, a(-)=0$  and  $a(+)=0, a(-)=1$ . Because of the linearity, adding other versions cannot affect anything about these states, including the CL and “agree.”)

### The Smeared-out Baseball Problem.

Typically the wave function for the c.m. of a macroscopic object spreads out in time. So after the passage of a suitable amount of time, the wave function could be smeared out over a macroscopic distance. According to many physicists, the implication is that quantum mechanics does not always lead to the perception of sharply localized macroscopic objects. But that is not correct; using essentially the same reasoning as in the S-G case, one can show that quantum mechanics always leads to the perception of a sharply localized macroscopic object.

Before starting the analysis, consider the uncertainty principle for a macroscopic object of mass  $m$  of about 1 kg and an observation time of about 1 sec. Then the spread in the c.m. coordinate during that time is gotten from

$$\Delta x \Delta p = \Delta x m \Delta x / \Delta t \cong \hbar \quad (9)$$

which implies a  $\Delta x$  of about  $10^{-17}$  meters, and that is negligible in this context.

We now observe a baseball which has its c.m. coordinate localized to, say, .01 mm. We observe it with a telescope at some distance and suppose the mounting of the telescope is calibrated in such a way that it gives a different angular reading each time the localized baseball is moved .01 mm.

Suppose next we have a baseball which has its c.m. spread out over 1 meter and we perceive it with the telescope. We can, without serious error, change the c.m. wave function to a sum, with the c.m. of each term in the sum being localized to within .01 mm.

$$|\Psi\rangle = \int dx \psi(x) |x\rangle = \sum \int_{x(i)}^{x(i+1)} dx \psi(x) |x\rangle \equiv \sum |\varphi(x(i))\rangle, \quad x(i+1) - x(i) = .01 \text{ mm.} \quad (10)$$

The observer focuses the telescope on the baseball and looks at the angular reading, with her neural firing pattern changing each time there is a different reading. After observation, our system consists of the baseball, the baseball-to-telescope photons, the telescope with its readings, and the observer, with her neural firing patterns (different for each reading of the telescope);

$$|\Psi\rangle = \sum |\varphi(x(i))\rangle |\text{photons corresponding to } x(i)\rangle |\text{telescope with reading } r(i) \text{ corresponding to } x(i)\rangle |\text{obs neural pattern corresponding to reading } r(i)\rangle \quad (11)$$

Each of the neural states of the observer in the sum is orthogonal to all the other observer states because of the different neural firing patterns.

Thus we arrive at a particular instance of Eq. (6). Each version of the observer will see a localized (to within .01 mm) baseball with sharp edges and sharp features (because feature and edge locations in each version are relative to the sharply localized c.m. location in each version). Again, we ask the observer to write CL if she perceives a localized, sharply defined, single-version, classical baseball and NON-CL if she perceives anything else. The result, according to Eq. (6), is that only CL is written.

$$|\Psi\rangle = \sum |\varphi(x(i))\rangle |\text{photons corresponding to } x(i)\rangle |\text{telescope with reading } r(i) \text{ corresponding to } x(i)\rangle |\text{obs neural pattern corresponding to reading } r(i); \text{ CL}\rangle \quad (12)$$

So we see that quantum mechanics itself implies only a classical, localized baseball will be perceived. The spreading of the wave function means that if the experiment is repeated, the observed location of the c.m. may change, but it does not imply that a smeared-out baseball will be perceived on a given run of the experiment.

### Summary.

Quantum mechanics allows many potential versions of reality to simultaneously exist in the wave function so we might suspect the unamended theory implies we should perceive more than one version of reality. Further, quantum mechanics allows the center of mass of a baseball to be spread out over a macroscopic distance so we might suspect the theory leads to the perception of blurred, spread-out baseballs. And in fact, these concerns are part of the motivation for particle and collapse interpretations.

However, the different versions of reality are in different, non-communicating “universes” so the different versions of the observer can only *report* that they perceive a single version of reality or a sharply localized baseball.

Further, different observers will never disagree on the version of reality perceived. Thus quantum mechanics, by itself, never leads to the reportable perception of anything other than a classical world. Neither particles nor collapse were invoked in obtaining this result so our perception of a classical universe does not imply that any amendment of “pure” quantum mechanics is necessary.

### References.

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