

A NEW APPROACH TO THE MEASUREMENT PROBLEM OF QUANTUM MECHANICS¹

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ABSTRACT: Quantum Mechanics is typically divided into two parts: the unobserved amplitude given by the equations of quantum field theory and the observed measurement aspect. We argue that a better approach is insert a probability realm in the middle. The reason is that every measurement involves interactions with a complex environment where massive decoherence transforms the amplitudes into standard probabilities. The probabilities eliminate complex superpositions so that quantum states A AND B become classical states A OR B. Thus the measurement process becomes a simpler and more familiar process of the observer selecting from classical type probabilities. This is close to the approach recommended by Henry Stapp. We anticipate that by using this approach many of the different interpretations of quantum mechanics become more similar to each other.

KEYWORDS: Interpretations of QM; Decoherence; Measurement; Quantum mechanics; Stapp

1) INTRODUCTION

An early version of this paper was given as a talk at the November 3, 2017 FoM5 conference in San Francisco. The talk was in the section celebrating Henry Stapp's new

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book “Quantum Theory and Free Will”. It was also part of a celebration for Stapp’s 90th birthday. We look forward to further exchanges of papers such as the present one, on topics relevant to Stapp’s interests.

Much has been written about the quantum measurement problem because there continues to be disagreement on the meaning of the fundamental aspects of the theory of quantum measurement. Quantum mechanics (QM) can be thought of as having three realms:

Realm 1: evolution of amplitudes, quantum field theory.

Realm 2: probability

Realm 3: perception

It is common to combine Realms 2 and 3, but we will join Abner Shimony (2004) in keeping those two realms separate. One benefit of separating Realms 2 and 3 is that whereas Realm 3 is purely classical, with no quantum superposition, Realm 2 does have a quantum like sum of probabilities where a cat can be a superposition of 50% chance of being alive and same for dead, with a negligible chance of being in a state of alive and dead. For Realm 2 there is no more superposition, that cat is alive or dead.

There is general agreement on Realm 1 being emergent from the domain of the Standard Model with 18 particles. See https://en.wikipedia.org/wiki/Physics_beyond_the_Standard_Model for a figure showing the 18 particles. However the physics levels that have greater relevance to quantum measurement are the complex physics and chemistry factors relevant to the biology of brain operation. In our approach there are two basic transitions: going from Realm 1 to Realm 2 by the decoherence mechanism, and then going from Realm 2 to Realm 3 by a mechanism similar to that of Stapp’s Orthodox von Neumann collapse. Stapp’s specific approach will be the theme of a separate paper that will be part of a celebration of his 90th birthday.

Section 2 of this paper will show how the quantum to classical probability transition can be made explicit by introducing a new criterion for “full” decoherence. John Bell’s approach was to not worry about the precise location for the collapse and to simply say that for all practical purposes (FAPP) it can be done by sufficient interaction with the environment (decoherence). But how does one pin down the FAPP location? Our strategy is to replace FAPP with FLOUP (For Lifetime Of Universe Purposes). The big advantage of FLOUP is that it places a calculable point at which the density matrix becomes a classical probability, as will be discussed in Section 2. We will follow Zurek in arguing that standard quantum field theory can fully account for the transition from Realm 1 of amplitudes to Realm 2 of probabilities.

Section 3 of this paper will focus on the aspect that goes from Realm 2 (probability) to Realm 3 (perception). We will focus on Stapp’s version of orthodox von

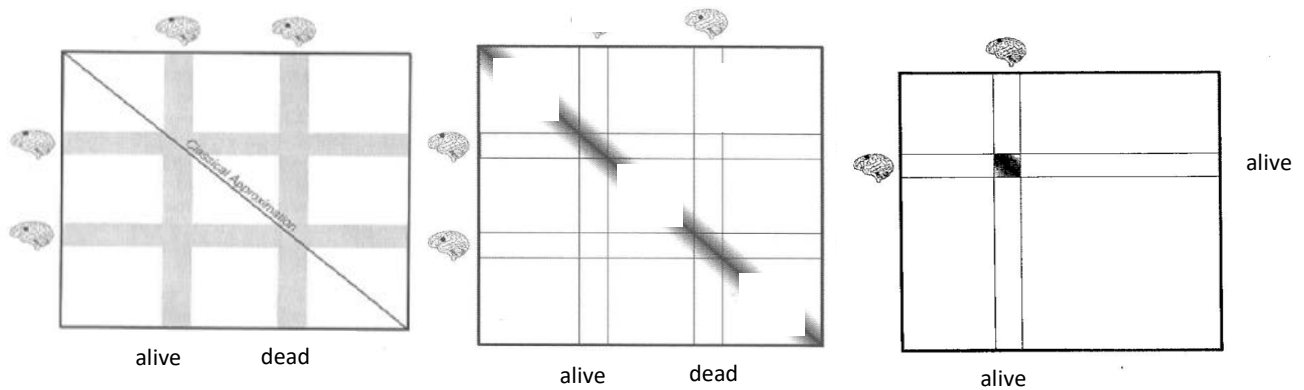
Neumann/Wigner with an infinite speed collapse of the probabilities to a single perception. We will argue that the Time Symmetric view of de Beaugregard/Aharonov and possibly the Transactional Interpretation of Cramer/Kastner are actually not that different from Stapp's version. Section 3 will also feature Neisser's Analysis by Synthesis because of the revolution his 1967 book "Cognitive Psychology" created. It fits in very nicely with Stapp's question asking approach for the outcome selection that is related to mind and cognition, and that enables the transition from Realm 2 to Realm 3.

2) AMPLITUDE TO PROBABILITY TRANSITION

In order to make sense of the complexity of the topic, especially for non-physicists, it is very useful to have a visual understanding of the density matrix for any quantum state. The density matrix visually captures the type of entanglement that is present. An excellent way to understand this topic is to look at the three density matrices in Henry Stapp's book: "Mindful Universe", shown below. Von Neumann invented the density matrix as a useful way of visualizing the three stages of QM processing, represented in Figs. 11.2, 11.3 and 11.6. The density matrix has become a standard tool for visualizing QM outcomes. Fig. 11.2 is the initial density matrix representing the neural activity across the brain. The density matrix is always symmetric with the value of each pixel being related to the QM amplitude of whatever is being represented. The mirror image values across the diagonal symmetry axis are complex conjugates of each other. Thus points on the diagonal have real values. The gray horizontal and vertical bars represent neural activity for seeing a cat 'alive' vs 'dead'. At the very beginning of processing there are many active neurons involved. Fig. 11.3 shows how decoherence, due to interaction with the environment, causes the density matrix to be concentrated near the diagonal. By "environment we include the processing by the eye of the creature sending the information to the brain. We think that instead of the full diagonal for the middle panel there could be two small boxes on the diagonal with 50% probabilities for "alive" or "dead". One might have thought that there would also be off diagonal probabilities for "alive" + or - "dead". Ruth Kastner (2014) has raised this point in connection with the density matrix for the "alive" and "dead" cat. She points out that the two off-diagonal small boxes would be strongly suppressed by the decoherence mechanism because that sort of outcome has low likelihood of being possible. The suppression would be so strong as to be made negligible.

Finally, Fig. 11.6 shows that when Nature (or Mind) responds to the viewer's "looking", the density matrix collapses to a small point, and then the three step process across Realms repeats.

In the two months since our FoM5 presentation that focused on decoherence we have been reading Zurek's articles on that topic. His 1991 article in *Physics Today*, titled



“Decoherence and the transition from quantum to classical” is useful reading for anyone interested in the interpretations of QM. He goes into important details of how to do the calculations for the density matrices. We strongly recommend reading that article together with his 2002 article “Decoherence and the transition from quantum to classical – Revisited”, published in *Los Alamos Science*. Most of the second article is identical with the first. However, there are many places in that second article where the wording is not only cleaned up but paragraphs are rewritten with new emphases. We strongly recommend reading that pair of articles just for the purpose of seeing those changes. They are partly stylistic changes but a number are deeper changes. In addition certain sections are removed (like the Gell-Mann/Hartle interpretation) and there are 6 substantial new insertions. The very last insertion is a full page new summary titled “The Existential Interpretation” that is a full-fledged new interpretation of QM in which decoherence is claimed to be between a Stapp/Bohr interpretation and a Many Worlds/Many Minds interpretation. The article by Zwolak, Riedel & Zurek (2016) is also useful to look at, largely because of its many citations to Zurek’s recent work on this topic.

The main new item that we would like to emphasize regarding Realm 2 is the size of the width of the diagonal of the density matrix. The density matrix mathematics implies that as the state of the system gets more and more entangled with the environment the density matrix gets closer and closer to the diagonal. That is, the

width gets more and more narrow. John Bell pointed out that at some point the width is so narrow that for all practical purposes (FAPP) there is no relevant difference between it being just on the diagonal. A diagonal density matrix is precisely the type of probability that is predicted by classical physics. The big problem is that one person's FAPP may be different from another person's FAPP. The idea here is that when things become entangled it is in principle possible to unentangle them by very costly, nearly impossible experimental procedures. We think that FAPP should be retired from these discussions and replaced with FLOUP (For Lifetime Of Universe Purposes). Most entanglements are sufficiently complex that our universe's lifetime is too short to reverse the entanglement. A look at: https://en.wikipedia.org/wiki/Future_of_an_expanding_universe indicates that after 10^{14} (100 trillion) years does not provide sufficient time to reverse most all entanglements. The point is that the density matrix will become FLOUP diagonal, indiscriminable from what it would be classically. It would be the same as having an infinitely thin diagonal density matrix.

As mentioned earlier, in addition to being infinitely thin, the density matrix will also have standard classical types of states. Thus Ruth Kastner (2014) points out that the environmental selection is expected to zero out states like Schrodinger's cat being in a state of "alive and dead". The probability for that type of state gets so very, very close to zero that there is no chance of finding that state FLOUP. Basically, For Lifetime Of Universe Purposes, our world makes the sort of classical sense with which we are familiar.

One of the projects that we would like to do in celebration of Henry Stapp's 90th event is to start learning how to do the calculations for how many seconds does it take for neural activity in our brains to become classical, FLOUP. We expect it to be substantially less than one second.

3) TRANSITION FROM PROBABILITY TO ACTUALITY

The notion of having three realms: amplitude, probability and perception is not commonly found. A more standard view is that there are two realms (amplitude and perception) with a shiftable boundary such as what von Neumann (1932) did in his "Mathematical Foundations of Quantum Mechanics". The last chapter of his book is titled, "The Measuring Process." In that chapter he combines Realms 2 and 3. Starting on p. 219 he provides the example of wishing to measure a temperature using a mercury thermometer. He says: "*no matter how far we calculate – to the mercury vessel, to the scale of the thermometer, to the retina, or into the brain, at some time we must say: and this is perceived by the observer.*" This is his version of the moveable cut for which he thanks conversations

with Szilard and Heisenberg. Von Neumann divides the measuring process into two parts. Process 2, the “observed” aspect is what we’ve been calling Realm 1, governed by QM amplitudes. Von Neumann’s Process 1 is the “observing portion of the world”. We have been dividing Process 1 into two parts: Realms 2 and 3. Before a year ago we would not have thought that Process 1 needed to split into two parts. But about a year ago we read Abner Shimony’s review (2005) of Michael Epperson’s book “Quantum Mechanics and the Philosophy of Alfred North Whitehead”. That strongly worded review made a dramatic switch in our thinking about the measurement problem. Shimony stressed what he called “*The Selection Problem*”, whereby the outcome of the observed entity is not a probability. After the process of decoherence the quantum theory predicts the probabilities of various outcomes, but not which outcome will arise.

One might think that it is possible to avoid decoherence by doing experiments where care is taken to avoid interactions with the environment. For example, consider the detection of a photon by the human eye, with care taken that the photon had no interaction with other particles. But it would be normal to consider the measurement to be done by the brain, not the eye. By the time the signal reaches the brain it will have interacted with many stages of neural processing that would be sufficient for decoherence to take place.

I have come to agree with Shimony’s strong concern for the *Selection* problem. The dramatic challenge of going from probability to perception should not be ignored. Shimony points out that FAPP considerations enable one to invent a criterion for the density matrix to be close enough to the diagonal to consider the measurement to have been made. But he is not content with that approach, because of its ambiguity. Our contribution is to replace FAPP with the concrete lifetime of universe purposes (FLOUP) as discussed earlier. Thus there is a calculable stage of the evolution of the density matrix at which point the sum of the off-diagonal probabilities of the density matrix are too small to be detected FLOUP.

We would like to consider some alternatives that have been suggested by folks who don’t like the infinite speeds used by von Neumann. A tidy alternative to the von Neumann story are what are sometimes referred to as the time symmetric (‘zig-zag’) interpretations of QM, proposed by de Beaugard and more recently by Aharonov. Consider the photon that is caught by the eye in the above example. The eye would send a photon signal backwards in time to the source, retracing its step perfectly and informing the emitter that it was absorbed so it should cancel sending it out elsewhere. That interpretation of QM has become somewhat popular. The mathematics for that zig zag is elegant, but going backwards in time although elegant doesn’t seem that much more rational than sending the information at an infinite speed. The Transactional Interpretation of QM by Cramer and Kastner has a similar type of

approach. The original Bohmian interpretation with hidden variables has no problem with this topic since the hidden variables have information about where the photon was destined to go. We look forward to gaining a better understanding of Bohm's more recent Implicate Order approach. We look forward to discussing that with Basil Hiley as part of our plans of having papers written for Stapp's 90th birthday publishing event.

Let's get back to the Zurek topic of entanglement with environment. We have a situation of FLOUP probabilities. How do we get actualities? One possibility is that there is an aspect to the universe that we've mentioned earlier in connection with Henry Stapp. Namely the topic of Mind. It could be that there is an aspect of the universe that is connected with animal brains, called mind. That aspect can solve not just one mystery, but two. In addition to the quantum selection problem of going from probability to perception, there is also the problem of subjectivity, sometimes called qualia or consciousness. The idea here is that sentient creatures, not just humans, have the special capacity for actualization from the probabilities and this ability could be connected to qualia.

We would like to point to an interesting possibility that is very close to Stapp's language. Suppose the sentient creature, let's simply refer to it as a human, is doing a face recognition task. On page 9 of Stapp's new book "Quantum Theory and Free Will" is the following text: "The whole process resembles, as emphasized by Wheeler, the game of twenty questions in which a succession of Yes/No questions is posed, with each eliciting 'Yes', or a 'No' response. " Then later on the same page he says: "This two-phased process allows our human conscious choices to enter causally into the evolution of the matter-based aspect of the world, rather than being helpless witnesses of a flow of events completely determined by the material aspects of nature alone." He clarifies the subjective experience on p. 25 with: "A 'No' answer will result in a corresponding reduction, but no immediate experiential feedback. This omission leaves room for another query to be posed with no passage of physical time. Thus millions of 'No's' can be produced by Nature with (little or) no passage of measured physical time". We queried Stapp about the word 'millions' and he said he should have used a smaller number.

The above story got lots of bells ringing in my head. About 45 years ago when I switched from theoretical particle physics to vision science a must read book was Ulric Neisser's "Cognitive Psychology", first published in 1967. It was strongly influential in the major transition from Behaviorism in the 1960s. If one googles "when did behaviorism end" one will find pointers to Neisser's book. The aspect I vividly remembers is Neisser's inventing the phrase "Analysis by Synthesis". Consider seeing a face and want to recall who it is. The idea is that the subconscious brain synthesizes a

sequence of faces and asks: “is it Mary”, “is it John”, and so on until finally the best match is found. The notion of analysis by synthesis seems very similar to what Stapp is advocating for how mind works. In a sense he is reinventing “analysis by synthesis”. The nifty thing about this is that it can be done in Realm 3, where the probabilities are already classical.

While decoherence explains the transition from amplitudes to probabilities, it does not explain the transition from probability to perception. We do not yet deeply understand the probability to perception transition. For some, the answer that the transition is “random” seems sufficient, but others prefer to give a philosophical explanation. Some interpreters of quantum theory have supplemented the theory with a metaphysical property. For example, Henry Stapp suggests that a mind-like Nature performs the “selection,” and decides what outcome will be actualized to perception. Hence, it is important to distinguish between the realms of probability and perception, and not confuse them, since the realm of probability is fully within the theory of decoherence, while the realm of actualization to perception belongs to the philosophical foundations of the theory.

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