

# Against Objective Realism

Hal Swyers

*Senior Operations Research Analyst, Alexandria, VA*

Over 80 years after the development of quantum mechanics there is still confusion about its supremacy over classical mechanics as the framework for understanding the physical universe. This confusion appears to be rooted in the conceptual image of particles as objects in the classical sense. Many authors present a picture of the universe based on Boltzmann's "billiard-ball" atomic particles which possess definite properties of momentum and position, where observer independent quantities of the properties identify an instantaneous point like microstate in classical phase space. Quantum mechanics tells us to abandon phase space and to embrace a more appropriate infinite dimension complex Hilbert space which is home to the wave function of a particle. The benefit is Hilbert space allows us to identify superposition states which are composites of mutually exclusive outcomes of observed quantities and evolve those states over time. Non-commuting operations on the wave function give us observed values of a property; while simultaneously placing other properties in superposition states. The existence of superposition states and non-commuting observables are incompatible with the notion of a real billiard ball object which has a definite microstate in phase space. This fundamental incompatibility has generated numerous attempts to interpret quantum mechanics in the context of classical mechanics, and where the boundary between the two can be drawn. This paper reoffers we have to abandon the notion of a universe based on classical mechanics and objective billiard-ball particle realism in favor of a wave-function based quantum reality.

## I. INTRODUCTION: WE CAN OBSERVE ATOMS

Ernst Mach has historically gained notoriety as the leading scientist opposing Boltzmann's "billiard-ball" atomism [1]. In this era of modern microscopy where it is routine to take images of individual atoms it would seem the classical view of billiard-ball like atomic objects is as valid as ever. Surely one can look at the fuzzy picture of a crystal through a modern microscope and see the definite features associated with the atomic particles and declare there is no ambiguity regarding their position and momentum. Boltzmann is vindicated, Mach reviled, and the popular view of the world in terms of classical atomic objects would seem to be the proper context for physical discussion.

Although Mach certainly was not prescient in this capacity; he did challenge atomism with continuum mechanics [1] which heavily influenced Einstein and is reflected in the development of General Relativity as the theory governing the spacetime continuum. It is somewhat interesting Einstein apparently vacillated over these same issues. On one hand we have Einstein as an author of the molecular kinetic Theory of Brownian Movement [2], and on the other we have

the father of General Relativity which is most certainly not an atomic theory.

If anything, this demonstrates Einstein was at least a pragmatist and tried to limit his philosophical prejudices during his peak years. It also highlights how many people appear to view the world, one with distinct objects in an otherwise continuous background. This is the world we are accustomed to; it is a classical world, the world which can be understood in the context of Leibniz's clockwork universe Newton so much opposed [3] while at the same time making updated use of the latter's "corpuscles" [4]. It is also this classical framework which provides our traditional physical notion of objective realism and the world into which quantum theory as a Theory of Complementarity was cast [5].

## II. OBJECTIVE REALISM

We only need to look to the dictionary to develop a specific meaning of objective realism. First we have the definition of objective [6]:

*Objective - of, relating to, or being an object, phenomenon, or condition in the realm of sensible experience independent of individual thought and perceptible by all observers :*

*having reality independent of the mind  
<objective reality>*

Upon which we add the definition of realism [7]:

*Realism - a theory that objects of sense  
perception or cognition exist independently of  
the mind*

Where object can be defined as [8]:

*Object - something material that may be  
perceived by the senses*

These definitions provide the basis for what we mean by objective realism. Principally it is the idea the universe can be understood in a framework where material entities exist and behave independently of one's mental awareness. In this context, Boltzmann's billiard-ball atoms are objects with properties having definite values which evolve independently of any observer. This means in principle there is no intrinsic indeterminacy associated with any quantity associated with a property of an object like particle. In the strictly classical sense, all uncertainty is associated with the measuring apparatus and the process of measurement.

This is the understanding of objective realism, and objective reality, which comes into conflict with quantum mechanics. This is the kernel upon which we can build an understanding of the argument of Einstein, Podolsky and Rosen (EPR) [9].

### III. BETWEEN SCYLLA AND CHARYBDIS

EPR provided two very carefully stated definitions in their 1935 paper. One definition was for the idea of a complete theory [9]:

*Every element of the physical reality must  
have a counterpart in the physical theory*

The second definition was for element of reality [9]:

*If, without in any way disturbing a system, we  
can predict with certainty (i.e. with  
probability equal to unity) the value of a  
physical quantity, then there exists an element  
of physical reality corresponding to this  
physical quantity*

This second definition is sometimes understood by the related term "counterfactual definiteness".

The definition of element of reality is puzzling for some, but one interpretation should be obvious. One can always predict with certainty the outcome of previously made measurements. Causality would tell us past measurements are not influenced by future measurements and thus have probability one of having a definite value, making them an element of reality in accordance with the definition.

However, another interpretation would tell us quantum mechanics cannot intrinsically satisfy this definition in regards to future measurements on unobserved systems. In this view, quantum mechanics does not tell us the value of a property to be measured in the future, nor can it be known by the universe at large, it instead tells us the quantity is one of many mutually exclusive possibilities. It goes even further and tells us certain quantities are complements of each other, such as momentum and position, and knowing one with definiteness precludes knowing the other with definiteness simultaneously. This differs drastically from classical mechanics, where in principle the unobserved quantity is well defined and intrinsic to the system and is known by the universe even if unseen by feeble human instruments.

Pauli, and Bohr, understood this situation very well by 1933 [5], two years before EPR published their paper. Pauli was careful to make the distinction between indeterminacy and ignorance. In classical mechanics, uncertainty is ignorance, in quantum mechanics, uncertainty is indeterminacy. Pauli even clearly described the situation as it applied to quantum mechanics on pg 7 of [5]:

*Due to the indeterminacy in the property of a  
system prepared in a specific manner (i.e. in a  
definite state of the system), every experiment  
for measuring the property concerned  
destroys (at least partly) the influence of a  
prior knowledge of the system on the (possibly  
statistical) statements about the results of  
future measurements.*

Here we see the roots of EPR's argument and why they were careful with their definition of the element

of reality. By its very nature, quantum mechanics cannot meet the restrictive definition of element of reality as provided by EPR. Armed with their ad hoc definition EPR offered their dilemma of [9]:

*(1) The quantum-mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality*

Their claim is they first proved this dilemma existed, and then demonstrated if starting with (1) as false; there is a situation in which (2) is also false, leading to an apparent contradiction.

On the basis of the EPR “paradox” and EPR’s interpretation of having demonstrated quantum theory as incomplete, various hidden variable theories emerged in order to fill in the apparent gap in dynamics left by quantum mechanics.

However, in the formulation of the “paradox” a third possibility was not considered in which classical descriptions of reality were actually too constrained to contain quantum states of superposition or account for non-commuting observables, so in effect, it was classical mechanics which could not possibly provide for a complete description of the universe. It is this third possibility which would eventually be made apparent by the work of Bell [10] and further understood by the work of Greenberger, Horne, Zeilinger, (GHZ) and Shimony [11] when it was shown no hidden variable theory could ever replicate the results of quantum mechanics.

#### IV. A PICTURE IS WORTH A THOUSAND WORDS

It is important for us to understand the impact of the proofs developed by Bell and GHZ. To do so it is helpful to illustrate how different the conceptual frameworks of classical mechanics and quantum mechanics are.

In Figure 1, we have the classical picture of a particle in one dimension with its properties plotted in phase space at an instant in time. The position of the particle is one axis in phase space and the momentum

is another. The particle is said to be in a microstate which is identified as a point in the phase space. In principle, any additional independent properties of the particle can be plotted on as many orthogonal axes as required in order to describe the complete microstate of the system.

From this conceptualization we can get a picture of what is meant by hidden variable. The idea behind hidden variables is there are additional axes in some phase space which are not readily apparent but in fact store additional information about the microstate of the system.

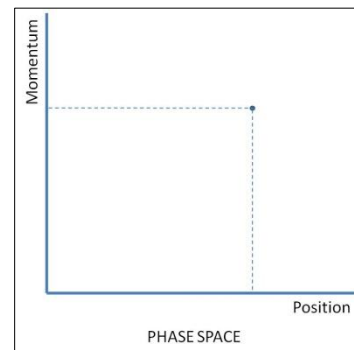


Figure 1. At any instant, a classical particle has a definite position and momentum in phase space

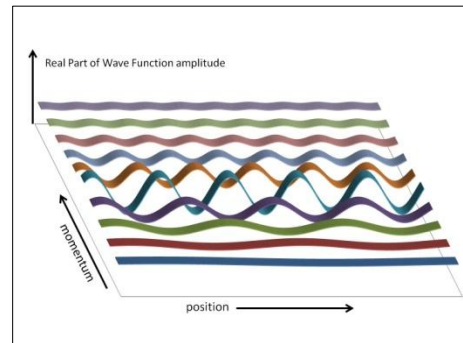


Figure 2. Non-normalized decomposition of a wave function in a representation of Hilbert space; the real part of particle wave packets are sums of independent trigonometric functions like sine and cosine.

The picture of Hilbert space is more complicated, Figure 2 is a representation of Hilbert space showing the decomposition of the real part of a wave function into independent basis functions, these functions are simple trigonometric functions such as sine and cosine. Each basis function extends for infinity in the position coordinate, and each function represents a momentum state. Similarly, a particle wave packet in

one dimension can be understood as the sum of complex basis functions having both real and imaginary components [12].

Figure 2 is useful because it lends itself readily to direct comparison with Figure 1. First one can see the representation of a particle in one dimension in Hilbert space is distributed along both momentum and position axes and fills the entire space. This can then be used to explain the idea of indeterminacy. Determining a definite position would require the summation of an infinite number of basis functions representing momentum, whereas the determination of momentum would require us to select a basis function which extends infinitely throughout the position dimension. This then gives us a way to understand the idea of uncertainty and the discrete nature of quantum mechanics. The discreteness emerges as one accepts uncertainty in a particle's position in exchange for limiting the components of momentum. Alternatively, one accepts additional components of momentum in exchange for limiting the probability for where one would likely detect a particle [13].

This representation of the wavy nature of the wave function in Hilbert space provides a mental image as to why the framework of quantum mechanics is distinctly different from the framework of classical mechanics and incompatible at a fundamental level. It also shows superposition and non-commuting observables are natural to quantum mechanics. So it is of major significance when the predictions of quantum mechanics cannot be made by classical theories using hidden variables as proved by Bell and GHZ based on the arguments specifically using superposition and non-commuting observables [10-11].

## V. A VOICE FROM BEYOND

In a famous lecture the late Sidney Coleman argued in favor of quantum reality [14]. In the lecture he provided first a defense of the locality of quantum mechanics, by pointing out the absence of interaction Hamiltonians in the GHZ argument (~32:00 in [14]). He further added it is *either* quantum mechanics *or* superluminal transfer of information and not both. However, since no local version of classical mechanics can explain the

outcomes of quantum experiments, and admitting non-locality would completely contradict the results of relativity in classical experiments, one is left with the conclusion of local quantum mechanics as being the correct and only option over any non-local classical alternative. Coleman then provided a description as to what quantum reality was (~46:00 in [14]):

*I will argue that there is:*

*NO special measurement process*

*NO reduction of the wave function*

*NO Indeterminacy*

*NOTHING probabilistic in quantum mechanics*

*ONLY deterministic evolution according to Schrodinger's Equation*

Key to this view is an understanding of the work of Neville Mott [15]. Mott explicitly showed how through the application of wave mechanics on its own, one could derive only atoms lying in a straight line would be ionized by an emitted alpha ray, even though the ray had a spherical wave function. Mott was able to do this without resorting to any reference of the alpha ray as a particle until a final interpretation was required. As Mott put it:

*If, however, we consider the  $\alpha$ -particle and the gas together as one system, then it is ionized atoms that we observe; interpreting the wave function should give us simply the probability that such and such an atom is ionized. Until this final interpretation is made, no mention should be made of the  $\alpha$ -ray being a particle at all.*

This one statement encompasses the point of Coleman's lecture, if one considers everything as one system, and not as a classical system where real billiard-ball particle objects move in some background space, and applies Mott's argument to our ordinary experience, we can see evolution of the wave function gives us the perception we observe definite outcomes to experiments. It is an *interpretation* when we think what we observe is due to real objects, but the interpretation is not a reflection of what actually happened, which was

deterministic evolution of the wave function according to Schrodinger's equation.

## VI. CONCLUSION: IT IS WHAT IT IS

Although over 80 years have passed since the development of quantum mechanics, it should not be discouraging it still has not reached its proper place as the dominant framework to describe the physical universe. Classical mechanics, even if only in its "proto-stage", has dominated human thinking for thousands of years. It might even be argued we have evolved to think of the world in terms of classical mechanics. Whether it is natural for us to see the world this way is one thing, but to deny how the world works when faced with the evidence is another. Objective reality where billiard-ball like particles move about in a classical spacetime continuum, as envisioned by EPR, simply is not an accurate vision of the universe.

It might be further argued we cling to our classical prejudices out of convenience, and this argument has

merit. It is certainly not surprising classical physics is easier to comprehend and can provide workable answers to many practical problems. However, the point of the argument here is if we really want to push beyond the intellectual boundaries of the world, then a thorough understanding of how our quantum reality works is required.

## REFERENCES

- [1] J. Blackmore, *Brit. 7. Phil. Sci.* **36**, 299-329 (1985)
- [2] A. Einstein, *Investigations on the Theory of the Brownian Movement*, (Dover Publications Inc, New York, 1956)
- [3] E.B. Davis, *S & CB* **3**, 103-117, (1991)
- [4] I. Newton, *Phil. Trans.* **7**, 5084-5103 (1672)
- [5] W. Pauli, *General Principles of Quantum Mechanics*, (Springer-Verlag, Berlin-Heidelberg-New York, 1980)
- [6] Merriam-Webster, *Objective*, <http://www.merriam-webster.com/dictionary/objective> , accessed on 8/29/2012
- [7] Merriam-Webster, *Realism*, <http://www.merriam-webster.com/dictionary/realism> , accessed on 8/29/2012
- [8] Merriam-Webster, *Object*, <http://www.merriam-webster.com/dictionary/object> , accessed on 8/29/2012
- [9] A.Einstein, B. Podolsky, N. Rosen, *Physical Review* **47**, 777-780 (1935)
- [10] J.S. Bell, *Physics* **1**, 195-200 (1964)
- [11] D.M. Greenberger, M.A. Horne, A. Shimony, A. Zeilinger, *Am. J. Phys.*, **58**(12), 1131-1135 (1990)
- [12] S. Brandt, H.D. Dahmen, T. Stroh, *Interactive Quantum Mechanics*, (Springer, USA, 2003)
- [13] Trans. Col. LEX, *Who is Fourier?*, (Language Research Foundation, Boston, 2002)
- [14] S. Coleman, [http://media.physics.harvard.edu/video/index.php?id=SidneyColeman\\_QMIYF.flv](http://media.physics.harvard.edu/video/index.php?id=SidneyColeman_QMIYF.flv), accessed on 8/29/2012
- [15] N.F. Mott, *Proc. R. Soc. Lond. A*, **126**, 79-84 (1929)