Quantum Mechanics

Particles Never Exist In Two Places At Once

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Overview

I felt somewhat compelled to write this little ditty due to my somewhat frustration of the prevalence of so much misunderstanding and nonsense associated with Quantum Mechanics.

It is quite clear that, although there are innumerable higher/better qualified Quantum Mechanics than yours truly, many of them simply fail to understand that their waffles, which are actually *classical* descriptions, are trivially contradictory to Quantum Mechanics.

The fundamental issue is the failure to understand that a quantum state vector such as $|X\rangle$ does *not* refer to a measurement of position X, but only to the *probability* of measuring a position, $P(X)$.

Explanations invariably confuse the two, and make arguments about the state vector *as if* it was identically equivalent to discussing the actual position of an object, instead of what it actually is, to wit, only a description of the probability of obtaining a position of an object.

The Problem

A BBC2 episode of Horizon "What Universe Are We In" 2015, illustrates the problem. Professor Seth Lloyd PhD., in explaining the double slit experiment produces the usual standard twaddle "the electron went through both slits at once". The notable Professor Lawrence Krauss PhD also advocates this view in more than one YouTube posted debate.

Unfortunately, such a statement is indisputable false, according to standard Quantum Mechanics. The fundamental issue is that there is a general refusal to accept that the universe is subject to Quantum Mechanics, not Classical Mechanics. It is a "new" result or axiom that stands on its own and can not, in principle, be "explained" by any type of classical reasoning. For example, …well if the particle did this, to account for that… it must do this…

If this classical type of argument is applied to the double slit experiment, the result is a result that contradicts the axioms of Quantum Mechanics. The basic mathematics of Quantum Mechanics is settled, irrespective of any ad-hoc metaphysical interpretations to the mathematics. Quantum Mechanics states that the result of any measurement, i.e. a true physical fact, is that a measurement can only result in a single eigenvalue. Applying the rules of Quantum Mechanics, unequivocally states that the probability of a particle being measured, i.e. a true physical fact, to have, say, both spin up and spin down simultaneously is *zero* (see appendix). This means, absolutely, that if Quantum Mechanics is correct, a particle cannot be in two locations at the same time. Period.

This is so simple and obvious, that I would guess that most would be going, wow…if it is so trivial under the standard rules of Quantum Mechanics, that two at once is a no no, why do so many "experts" tout all this metaphysical claptrap? One can only conjecture…

So, rather than the typical waffle of "…this physical explanation of the two slit experiment proves that a particle can be in two places at once" the argument, essentially, is an argument that *proves* that classical mechanics is false. Quantum Mechanics gives the correct answers, Classical Mechanics does not. It’s that simple.

<u>The Roots To Confusion</u>

One of the most common sources of misunderstandings is the widespread inability to understand what the symbols of Quantum Mechanics equations actually mean, and how to manipulate those symbols. For example, consider Boolean algebra.

The Boolean equation:

Y= A+B

Where A=1 and B=1

Results in:

Y=1

Not 2

Because the “+” operator in the context of Boolean algebra *has a different definition and meaning*, than that in ordinary arithmetic. Similarly, the “+” sign in Quantum Mechanics is also *not* an arithmetic operator; it is a probabilistic Boolean OR operator.

The equation:

$$|\varphi\rangle = a|X_1\rangle + b|X_2\rangle$$

Is a statement that the vector

$$|\varphi\rangle$$

Will be either the vector:

$$|X_1\rangle$$

OR the vector:

$$|X_2\rangle$$

It does not mean that there is a physical sum, where both vectors are argued to exist simultaneously in the physical world. In fact, a “sum” wouldn’t even cut it, it would need to be a logical, probabilistic AND function!

Furthermore, it is stressed that the vector $|X_1\rangle$ is not X_1.

This last point, whilst pretty much trivially obvious in the context of the rules of Quantum Mechanics, seems to have completely escaped many. The *quantum state* represented by $|X_1\rangle$ *is not the same classical state* represented by X_1. Confusion as to what a state means in Quantum Mechanics is usually at the heart of most waffle descriptions as to what QM means.

In classical mechanics, equations refer to, for example, the actual physical positions given by X. That is, the *classical state* is represented by X.

In Quantum Mechanics, state equations only represent the *probability* P, for example, of obtaining X. That is:

$|X\rangle \rightarrow P(X)$ not $|X\rangle \rightarrow X$

That is, a *quantum state* is represented by $|X\rangle$ and its associated probability, $P(X)$ of X is not X itself.

The vector $|X\rangle$ itself has no direct or "instantaneous" meaning in an equation. It only has a meaning with respect to, what values of X are allowed, and what is the probability that such X's are obtained in a final calculation.

Understanding these points is key to understanding why a statement such as "the state vector is in a superposition of states" does not mean that, for example, a particle is actually in two X positions at once. It simply means that there is a *probability* that the particle may be at one X position *or* another X position.

Relative State

A key assumption in classical mechanics is that it is possible to assign unique values of properties to objects independent of the measuring system.

Quantum mechanical experiments prove this assumption to be false. It is thus surprizing that many "two places at once" arguments ignore this key point. For example:

https://en.wikipedia.org/wiki/Stern–Gerlach_experiment

The Stern-Gerlarch experiment proves that the assignment of unique numbers, say spin, to objects is false. It is simply impossible to label objects with characteristics independent of its measuring system. For example, the assumption of Newton that one can simple declare an object to have a unique mass, is therefore now known to be false. The Stern-Gerlach experiment shows that spin is a function of its interaction with other objects. The value of an electron's spin is not simply a function of the electron itself. Its spin is relative to what it interacts with. However, many misinterpret that this means that the object itself doesn't exist!

The point here is that the numbers assigned to objects are man-made. Nature has no such numbers. It only deals with the object. There is no demand of Gods that the numbers man assigns mean anything at all. Much erroneous debate has been made of this misunderstanding, e.g. the EPR Paradox on "elements of reality". Stern-Gerlarch proves that there is no general element of reality in the sense of assigning unique numbers to objects, but this does not mean that the object itself is not real.

Even in classical mechanics, an object may have many simultaneous values of measured velocity, despite actually only having one state of motion. Walking on the Earth at 5 mph, also means that you are moving at 67 kmph around the Sun.

It's Quantum Mechanics, Not Classical Mechanics, Dah…!

The reader should refer to the standard accounts of the two slit experiment for a general overview, for example, https://en.wikipedia.org/wiki/Double-slit_experiment.

A key feature of the experiment is that single particles are fired through the slits and the appearance of a diffraction pattern appears over time as many electrons build up a pattern. In an effort to explain this result *classically*, it is *assumed* that there are two wavicles at different positions on the imaging screen side of the two slit barrier. The maximum and minimum of the wave functions of these wavicles are then argued to interfere with each, other hence accounting for the variations in density of the electrons on the screen. It is thus argued that, as this is the only way to "explain" that there is a wave pattern on the screen, it "proves" that a single electron gets split up into two as it passed through the slits, and magically combines to one on hitting the screen…

The mathematical rules of Quantum Mechanics, independent of any physical interpretation, are absolute in that the probability of an observable having two simultaneous eigenvalues of position, is zero. So, if Quantum Mechanics is true, any argument that leads to declaring that "a particle is in two places" *must be false*. In this case, it means that the *assumption* that a particle splits up is false. There is no realistic way of escaping this conclusion.

The correct explanation for this dilemma is that physical reality cannot be explained by classical reasoning. *The universe is Quantum, not Classical.* There is simply no explanation from classical axioms that explains why there is a diffraction pattern, although there are physical explanations such as Bohmian Mechanics that do account for the results of Quantum Mechanics in a realistic way.

So, it is astounding that many experts, and sometimes major TV personalities, spout of the laws of Quantum Mechanics in the same sentence as claiming to the masses that particles are at many places at once. They are completely confused on the point that Quantum Mechanics and their waffle Classical descriptions are contradictory. They simply have not learnt to think Quantumly and are hopelessly trying to cling to their Classical baggage.

Quantum Reality

The reality of Quantum Mechanics, is that pretty much 99% of all professional practitioners of Quantum Mechanics simply don't concern themselves with waffle interpretations as to what is alleged to be actually happening. For the most part, it is irrelevant to the 90% of Physicists engaged in real world work designing new semiconductor processes, and the remainder engaged in designing the new legal high by simulations of the Shrödinger equation.

Many Worlds - Ho…humm…

Might as well put in my 1 cents worth on this topic…

Quantum Mechanics states that particles do not split up by the notion that all measurements must result in single eigenvectors and eigenvalues. Sure, it is possible to postulate that a particle split ups and vanishes into another universe, such that it cannot be measured in our universe, in order to avoid the inherent contradiction of the postulates of Quantum Mechanics and charge and energy conservation laws. However, if it cannot be measured, ever, it is simply irrelevant to our universe. We can never know, as any interaction that could "prove" alternate universes would constitute a measurement of charge or mass-energy violation in our universe, which would destroy the Quantum Mechanical argument that led to many worlds theory in the first place.

The MWI is, essentially, a sprit-soul interpretation. It states that there are invisible universes that contain other people that we can never detect. Its metaphysics.

Sabine Hossenfelder's take on MW is here [The Trouble With Many Worlds]

All interpretations, apart from the Copenhagen and Ensemble interpretations, typically attempt to give a classical, touchy-feely description to the experimental facts of Quantum Mechanics. The proponents of such interpretations are usually unable to remove the straightjacket clothed on them since childhood. They produce never ending classical pictures that try to "explain" how rational, common sense ideas can account for the strange results of QM.

Appendix

Derivation of the probability of the occurrence of two simultaneous observables.

For simplicity, consider the case of an electron having spin up or down.

Quantum Mechanics states that:

$$\text{Prob} = \langle \varphi | P | \varphi \rangle$$

Where P is the projection operator

The projection operator for the probability of two simultaneous observables A and B is given by:

$$P = P_A.P_B$$

The projection operator for the probability of spin operators A and B is given by:

$$P_A = |up\rangle\langle up| \text{ and } P_B = |dn\rangle\langle dn|$$

hence

$$P = P_A.P_B = |up\rangle\langle up|dn\rangle\langle dn| = 0, \text{as } \langle up|dn\rangle = 0$$

because $|up\rangle$ and $|dn\rangle$ are necessarily orthogonal to each other as they are eigenvectors of a Hermitian operator. hence, there is zero probability, according to standard Quantum Mechanics, of two simultaneous observables.

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