# Quantum Mechanics.

# The Ensemble Interpretation

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## Overview

These papers forms a brief outline to the Ensemble Interpretation of Quantum Mechanics. This interpretation is in basic accord with an interpretation held by Einstein, and in full accord with that championed by Leslie E. Ballentine, Professor at Simon Fraser University, and writer of the text book "Quantum Mechanics, A Modern Development" ISBN981-02-4105-4.

The Ensemble Interpretation, or Statistical Interpretation of Quantum Mechanics is an interpretation that can be viewed as a minimalist interpretation. That is, it is a quantum mechanical interpretation, that claims to make the fewest assumptions associated with the standard mathematical formalization. At its heart, it takes the statistical interpretation of Born to the fullest extent. The interpretation states that the wave function does not apply to an individual system, or for example, a single particle, but is an abstract mathematical, statistical quantity that only applies to an ensemble of similar prepared systems or particles.

The interpretation is summarized here:

*"The attempt to conceive the quantum-theoretical description as the complete description of the individual systems leads to unnatural theoretical interpretations, which become immediately unnecessary if one accepts the interpretation that the description refers to ensembles of systems and not to individual systems."*

*Einstein - Albert Einstein: Philosopher-Scientist, ed. P.A. Schilpp (Harper & Row, New York)*

Some of this paper is extracted from Ballentine's text book, although any errors and misinterpretations are this authors alone.

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## Main Interpretations

The are many interpretations of Quantum Mechanics. Apart from the standard Copenhagen Interpretation (CI) and the Ensemble Interpretation (EI), all of these alternatives attempt an explanation of the inherent indeterminacy of quantum mechanics.

The Ensemble Interpretation does not attempt any explanation as to why Quantum Mechanics is the way it is. It simply states a rational way of interpreting and calculating results without introducing the conceptual difficulties that are inherent in the Copenhagen Interpretation. It is essentially still, a shut up and calculate method.

The attraction of some of the other interpretations, is that it may be more often a case that it seems fashionable to believe in daft ideas.

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## Basic Meaning of "The Ensemble" and "The System"

The “ensemble” of the ensemble interpretation is identified by an ensemble of setting up and performing (essentially) the same experiment many times. This is referred to as an ensemble of systems. It is not, for example, an “ensemble” of performing one single experiment on a simultaneous set “ensemble” of particles. A group of particles as in a gas, is not the “ensemble” of the “ensemble interpretation”, although it is possible that a repeated set of ensemble experiments may involve a large “ensemble” of particles as its system.

The motivation for this view is that QM, by its complete acceptance of probability as its core foundational principals, inherently requires that repeated measurements must be performed in order to verify any of its probabilistic outcomes. A single throw of a dice always results in one single outcome out of many possible outcomes, such that a single throw can not verify that any outcome has for example, a probability of 1/6. In this manner, QM is no different from classical mechanics. If QM makes an *objective* probability prediction of a value occuring, there is no way to know if that probability is correct without effectively “repeating the experiment” and examining the values many times. One needs to be able to actually get a ratio of experimentally measured real numbers. A “probability object represents a single system” simply fails to make any logical sense.

However, it should be stressed that, in contrast to classical systems such as dice throwing and older ensemble interpretations, the modern ensemble interpretation as discussed here, specifically does *not* assume, nor require, that there exist specific values for the properties of the objects of the ensemble, prior to measurement. The ensemble interpretation makes claims as to final results, it makes little claim as to how those results arrived.

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## Ensample Interpretation

The Quantum Ensemble Interpretation states that the state vector applies to an ensemble of systems, not an individual system. It is an abstract concept.

That is, there is *no* individual system (particle) in a *real* combined "summed" state such as:

|phy> = |a> + |b>

Where |a> is interpreted in some naive way to directly relate to a physical property "a".

The state vector is simply a convenient notational way of mathematically *modeling* the physical situation, by mathematical objects that represent probabilities of results. It should be clearly noted that the "+" sign of a probabilistic equation is *not* an addition operator, it is a standard *probabilistic* or Boolean logical ***OR*** operator. The state vector is inherently defined as a *probabilistic* mathematical object such that the result of a measurement is one outcome **OR** another outcome.

**Meaning of the State Vector**

State vectors such as:

|phy> = |x1> + |x2>

describe, in a one to one mathematical to physical sense, the *probability* that, for example, a system is at position x1 OR position x1. A state vector is *not*

|phy> = x1 + x2

naively implying that, as in some popular accounts, a system might be in two positions simultaneously. If this were so, QM would write such an equation!

That is |x1> -> P(x1) *not* |x1> -> x1

The "State" of a system means, *the probability distribution of its possible results.* A summed state means that there is more than one possible value of a result on measurement.

Quantum Mechanics says *nothing* about individual results, only the probability of results. This is true in *any* interpretation of QM. This makes it, essentially, nonsensical to then argue that QM itself might imply simultaneous multiple values for values prior to measurements.

It is noted, that Quantum Mechanics first lead to the introduction of the Dirac notation, however, there is no technical reason why this approach may not also be applied to classical situations. Applying the notation to conventional statistics allows the Dirac notation approach to quantum situations to be clarified. For example, it might have been more apparent that the mathematics did not require a quantum system to be actually in simultaneous real physical states.

A simplest way to *illustrate* the concept is to refer to a classical ensemble.

Consider a classical dice. If the probability of the result of a thrown dices is expressed in Dirac notation, the following state vector or wave function may be written:

|psy>= (|1> + |2> + |3> + |4> + |5> + |6>)/sqrt(6)

It is clear that on each throw, only one of the states will be observed, but it is also clear that there is no requirement for a collapse of the state vector, or for the dice to *physically* exist in the *summed* state. The wave function is taken to be a *statistical* probability function, that does not directly apply to a single experiment, only the statistical results of many. Systems are never required to physically exist in the a "summed" state, it is just *notation* for a calculation method that only has meaning in calculating a final result. The psy function is a statement on the *possibilities* that might occur if a measurement actually takes place, not a statement of an objects physical existence prior to a measurement.

## Wave Particle Duality

The wave-particle duality is one of the most common misconceptions of Quantum Mechanics. Particles, apparently, are always particles and never waves. What they do do, is operate on the basis of Quantum Mechanics, not Newtonian Mechanics. Whether the phenomena is electrons or light, in a two slit diffraction experiment, what is always observed, are small localized impacts on screens that build up statistically in a pattern that is similar to that expected of continuous pure waves. Waves are no more than simply a convenient idealization used to approximate problems. For example, water waves, aren't. They are just collections of billions of water molecules behaving approximately as if they form a continuous substance. Electromagnetic waves, aren't. All E&M phenomena is described in Quantum Electrodynamics as the momentum exchange of photons.

Indeed, for there to be a wave, what is the medium? What is physically waving? Certainly the Michelson-Morley experiment's failure to detect the aether would appear to nail the lid on that particular coffin.

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## Heisenberg's Uncertainty Principle

The Heisenberg's Uncertainty Principle, HUP, is often understood to imply that individual simultaneous position and momentum determinations can  not be made.

The rigorous HUP statement is a *statistical* statement. It is a statement about the [1]*standard deviations of momentum and position*, not about individual measurements. Standard deviations are calculated from calculating the root mean square of many individual measurements. It says nothing about an individual measurement, indeed [2]Jauch (1993) performs such a measurement that is much more precise than that would otherwise be indicated by HUP. Indeed, the rigorous HUP is not even a statement about simultaneous [1]measurements.

Contrary, to some popular accounts, the exact (rigorous) derivation of uncertainty relating to [X,P], are not related to Heisenberg's statement of measurement errors. These derivations calculate the commuter based on *ensembles* of measurements. It is not clear that an exact derivation of  Heisenberg's "of the order of" for instantaneous measurements has ever been performed.

The HUP is about the *prediction* of a  state given the current position and momentum. It is *predictions* that are constrained by HUP, not measurements.

Indeed, Heisenberg admits that position and momentum can be known exactly. In Heisenberg's Chicago lectures of 1930, he writes:

"If the velocity of the electron is at first known, and the position then exactly measured, the position of the electron for times previous to the position measurement may be calculated. For these past times, $\delta p \delta q$ is smaller than the usual bound. (Heisenberg 1930, p. 15)

Heisenberg continues : "the uncertainty relation does not hold for the past".

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## Schrödinger Cat

Schrödinger's Cat was introduced to illustrate that one interpretation of the Copenhagen Interpretation of Quantum Mechanics had severe limitations. It achieved this, yet apparently, many simply failed to notice. The fact that a real cat can not be both dead and alive at the same time was simple ignored.

The key point of the Shrodinger cat argument was that, if it was taken that the state vector applied to a single system, then this would imply that at a large scale *macroscopic* level, that objects could exist in two states at once, for example a dial pointer being viewed at two positions several cm apart at once. That is, mysterious magical effects that are taken to be applicable only in the tiny quantum world, would inherently be manifested in the classical world. However, this is in contradiction to known experimental facts. Dial pointers have never been observed to do this. The intricacies of the cat experiment often confesses the basic point being made. The cat experiment was simply one method to illustrate how a single system state vector interpretation gets bootstrapped up into a situation known to be false. In order to try an circumvent this blatant contradiction, a new process was simply invented, specifically the "collapse of the state vector or wave function".

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## Collapse of the Wave Function

The collapse of the wave function or reduction of the state vector is not required in the ensemble interpretation, nor is it supported experimentally. No experiment has ever measured an object in two states simultaneously. Objects have only ever been measured in an eigen state, so claims that they do is unsupportable. Indeed, if it were possible to physically measure say, a particle in two positions at once, then QM would be falsified as QM explicitly postulates that the result of any measurement must be a single eigen value of a single eigen state.

In the ensemble approach, the notion of wave function collapses is just as meaningless as saying that because there is an average of 2.4 children to a family, that when a particular measurement on a specific family is made, the wave function collapses on a measurement to say, 2 boys and a girl.

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## No Two Places at Once

It is often stated that Quantum Mechanics implies that a particle can be in two places at the same time. This is experimentally unsupportable, and contradicts the postulates of quantum mechanics. Furthermore, at no time has *any* experiment *ever* been performed that detected co-incidence of the same particle in two different positions at once. Indeed, QM specifically prohibits such detection, in principle, as noted below.

One of the postulates axioms of QM, is that any measurement *can only* result in a *single* eigenvalue. For example, one unique position for an object. Therefore, any superfluous agreement that naively infers that an abject can be in two positions must be erroneous if QM is actually taken as correct. If QM is taken as false, than this would invalidate any "QM" argument that could be a possibility for an object to occupy two points at the same time.

The fallacy of the two simultaneous positions argument is not understanding that an argument, however plausible, if it results in a known contradiction, must be false. For example, suppose it was claimed that the Pope had sanctioned general abortions as being acceptable, it could not be concluded that this claim was valid. The question would be "Is the Pope Catholic?" . Since we know the Pope is indeed Catholic, and that the (assumption) Catholic church prohibits abortions, the facts dictate that the claim must be false.

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## Hidden Variables

The ensemble interpretation is distinct from the issue of "hidden variables", and as such, there is no requirement for objects to be assigned unique, defined properties, independent of measurement in the ensemble interpretation. Indeed, the notion that experimental results depend on the way the experiment is constructed, with hindsight, is trivially obvious. For example, no object can be said to have a definite velocity. The velocity of an object is clearly relative, and meaningless without referencing the exact experimental conditions that it was measured, e.g. the reference frame to which the velocity is measured. It is also trivially obvious that the lack of a distinct attribute for an object, such as velocity, does not imply that the object itself, does not exist!!!

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## Consciousness Observer Created Reality

This one is, frankly, quite daft. It makes no difference whatsoever, whether the physicist observes a double slit experiment or not. If he is outside smoking a cigarette, rather than watching his equipment dials, it makes not the slightest difference to the result, and never has such observer created reality ever occurred. The "observer" is the physical setup of the equipment, not the conscious observer.

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## Summary

It has been argued that the Copenhagen Interpretation of Quantum Mechanics is not supportable, either by experiment or logic.

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## Appendix

[1]Ballentine "Quantum Mechanics, A Modern development" P.225- P.226
(reference to graphs of delta_x and error_x, showing them not the same)

"...One must have a repeatable preparation procedure corresponding to the state p which is to be studied. Then on each one of a large number of similarly prepared systems, one performs a single measurement (either Q or P). The statistical distributions of the results are shown as histograms, and the root mean square half-widths or the two distributions deltaQ and deltaP, are indicated in fig. 8.2. The theory predicts that the product of these two half-widths can never be less then hbar/2, no matter what state is considered."

"To the reader who is unfamiliar with the history of quantum mechanics, these remarks may seem to belabor the obvious. Unfortunately the statistical quantities delta_q and delta_p in(8.33) have often been misinterpreted as the errors of individual measurements. The origin of the confusion probably lies in the fact that Heisenberg's original paper on the certainty principle, published in 1927, was based on early work that predates the systematic formulation and statistical interpretation of quantum theory. Thus the natural derivation and interpretation of (8.33) that is given above was not possible at the time. The statistical interpretation of the indeterminacy relations was first advanced by K.R. Popper in 1934."
(8.33) - delta_x.delta_p >=1/2|<C>|, the result hold for any operators that satisfy [A,B]=iC"

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[2]Ballentine "Quantum Mechanics, A Modern development" P. 225-226

"Jauch (1993). The rms atomic momentum fluctuation, delta_p is directly obtained from the temperature of the crystal, and hence gives a lower bound to delta_q, the rms vibration amplitude of an atom. The value of delta_x can be measured by neutron diffraction, and at low temperature it is only slightly above its quantum lower bound, hbar/2delta_p. Jauch stresses that it is only the rms ensemble fluctuations that are limited by (8.33). The position coordinates of the atomic cell can be determined with a precision that is two orders of magnitude smaller then the quantum limit on delta_q".

Jauch (1993) - Heisenberg's Uncertainty Relation and Thermal Vibrations in Crystals, Am. J. Phys. 61, 929-932

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http://www.phys.tue.nl/ktn/Wim/qm11.htm

Dr Willem M. de Muynck, Department of Applied Physics, Eindhoven University of Technology:

"A related consequence of a realist version of an individual-particle interpretation of the quantum mechanical state vector is that a microscopic object must split if the state vector does so. For instance, in neutron interference experiments of the type considered in Publ. 27 this would imply that a neutron traversing a neutron interferometer does so while being split into two halves, each of which taking a different path. Since this is in disagreement with all empirical data (strongly suggesting that each neutron follows either one path or the other) a realist individual-particle interpretation of the quantum mechanical state vector is unattractive (as is the "suspended animation" interpretation of the Schrödinger's cat state referred to above). It is quite remarkable that nevertheless this interpretation is widely entertained. This may be due to the popular idea of particle-wave duality, having been developed in the

Copenhagen interpretation during the early stages of the development of quantum mechanics, but being obsolete by now"

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*Von Neumann's projection postulate*

http://www.phys.tue.nl/ktn/Wim/qm1.htm#object-context

Dr Willem M. de Muynck, Department of Applied Physics, Eindhoven University of Technology:
Sometimes also *von Neumann's projection (or reduction) postulate*, stating that during a measurement of standard observable **A** the state vector |ψ> undergoes a discontinuous transition

$|\psi\rangle \dashrightarrow |a_m\rangle$

if the measurement result is $a_m$, is taken as part of the formalism of quantum mechanics. I do not consider von Neumann's projection (or reduction) postulate to be either a necessary or a useful property of a quantum mechanical *measurement*. It is not necessary, because it is a consequence of a certain *interpretation* of the quantum mechanical state vector (viz. a realist version of the individual-particle interpretation) that is dispensable. It is not useful because it is *not* satisfied by many practical experimental measurement procedures. For instance, an *ideal* photon counter detects photons by absorbing them. Hence, ideally the final state of the electromagnetic field is the vacuum state rather than the eigenvector of the photon number observable corresponding to the detected number of photons. Since photons that have survived the detection process are not registered at all, it follows that the functioning of the photon counter even depends crucially on *not* satisfying von Neumann's projection postulate: it is operating better to the extent it violates the projection rule. Consistency problems of quantum mechanical measurement, arising because of von Neumann projection, could better be dealt with by abandoning the postulate as a *measurement* principle, rather than by ignoring the existence of such well-tried measuring instruments like photon counters.

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Interesting Related Links:

Ulf Klein's website on the statistical interpretation of quantum theory

Ensemble Interpretations

Einstein's Reply to Criticisms

http://plato.stanford.edu/entries/qt-uncertainty/#2.3 - Analysis as to the real meaning of HUP.

On the Postulates of Quantum Mechanics.pdf

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