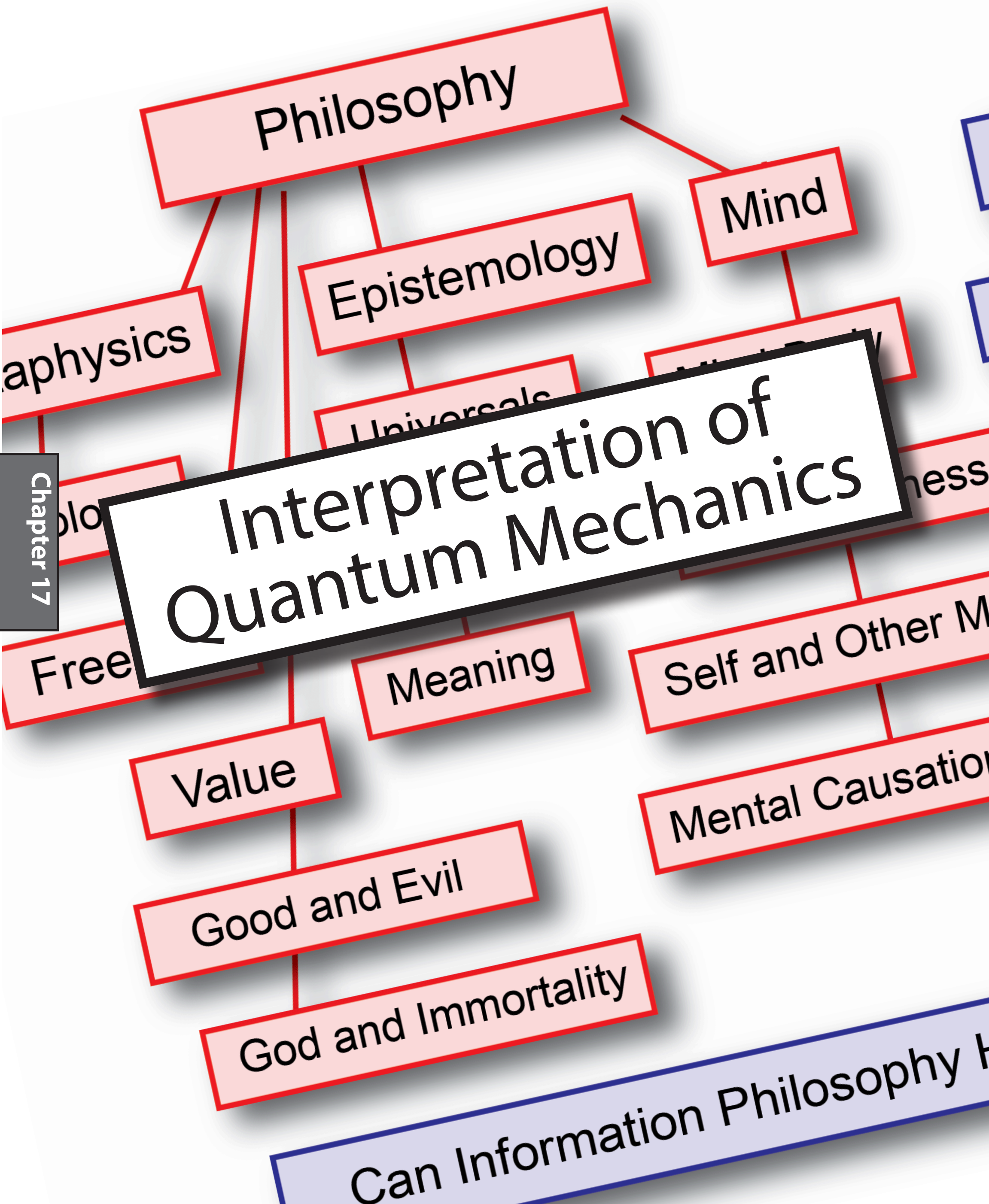
Chapter 17

Interpretation of Quantum Mechanics



This chapter on the web
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Information Interpretation of Quantum Mechanics

Our information interpretation is simply "standard quantum physics" plus information being recorded irreversibly. Unlike the Copenhagen Interpretation, we offer a *visualization* of what is going on in quantum reality, with animations (on-line) of the wave function evolution and the appearance of the particle, when the wave function shrinks to its minimum possible size h^3.

The information interpretation of quantum mechanics is based on three simple premises:

1) Quantum systems evolve in two ways:

• The first is the wave function deterministically exploring all the *possibilities* for interaction,

• The second is the particle randomly choosing one of those possibilities to become actual.

2) No knowledge can be gained by a "conscious observer" unless new information has already been irreversibly recorded in the universe. New information can be created and recorded in three places:

• In the target quantum system,

• In the combined target system and measuring apparatus,

• It can then become knowledge in the observer's mind.

3) The measuring apparatus is quantal, not deterministic or "classical." It need only be statistically determined and capable of recording the irreversible information about an interaction. The human mind is also only statistically or adequately determined.

• There is only one world.

• It is a quantum world, which only *appears* to be classical.

• The world only *appears* to be determined.

Ontologically, the quantum world is indeterministic, but in our everyday common experience it appears to be causal and deterministic, the so-called "classical" world. Information physics claims there is only one world, the quantum world, and the so-called "quantum to classical transition" occurs for any macroscopic object of mass m that contains a large enough number of atoms. For large enough systems, independent quantum events are "averaged over." The uncertainty in position x and velocity v of the large object becomes less than the quantum indeterminacy

$\Delta v \, \Delta x \geq h / m$ goes to zero as h / m goes to zero.

The classical laws of motion, with their apparent determinism and strict causality, *emerge* when objects are large enough so that microscopic events can be ignored, but this determinism is fundamentally *statistical* and physical causes are only probabilistic, however near they seem to certainty.

Information philosophy interprets the wave function ψ as a "possibilities" function. With this simple change in terminology, the mysterious process of a wave function "collapsing" becomes a much more intuitive discussion of ψ evolving to explore all the possibilities (with mathematically calculable probabilities), followed by a single actualization, at which time the probabilities for all non-actualized possibilities go to zero (they "collapse") instantaneously.

Information physics is standard quantum physics. It accepts the Schrödinger equation of motion, the *principle of superposition*, the *axiom of measurement* (now including the actual information "bits" measured), and - most important - the *projection postulate* of standard quantum mechanics (the "collapse" that so many unorthodox interpretations deny).

But unlike some interpretations, the conscious observer of the Copenhagen Interpretation is not required for a projection, for the wave-function to "collapse", for one of the possibilities to become an actuality. What the collapse does require is an interaction between systems that creates irreversible and observable, but not necessarily observed, information.

Among the founders of quantum mechanics, almost everyone agreed that irreversibility was a key requirement for a measurement. Irreversibility introduces thermodynamics into a proper formulation of quantum mechanics, and this is what the information interpretation requires.

Information is not a conserved quantity like energy and mass, despite the view of many mathematical physicists, who generally accept determinism and think information is a constant. The universe began in a state of equilibrium with minimal information, and information is being created every day, despite the second law of thermodynamics. Classical interactions between large macroscopic bodies do not generate new information. Newton's laws of motion imply that the information in any configuration of bodies, their motions, and the force laws, is enough to know all past and future configurations. Classical mechanics conserves information.

In the absence of interactions, an isolated quantum system evolves according to the unitary Schrödinger equation of motion. Just like classical systems, the deterministic Schrödinger equation conserves information.

Unlike classical systems however, when there is an interaction between quantum systems, the two systems become entangled and there may be a change of state in either or both systems. This change of state may create new information.

If that information is instantly destroyed, as in most interactions, it may never be observed macroscopically. If, on the other hand, the information is stabilized for some length of time, it may be seen by an observer and considered to be a "measurement." But it need not be seen by anyone to become new information in the universe. The universe is its own observer!

Compare Schrödinger's Cat as its own observer.[1]

For the information (negative entropy) to be stabilized, the second law of thermodynamics requires that an amount of positive entropy greater than the negative entropy must be transferred away from the new information structure.

Exactly how the universe allows pockets of negative entropy to form as "information structures" we describe as the "cosmic creation process." This core two-step process has been going on

1 see chapter 23

since the origin of the universe. It continues today as we add information to the *Sum* of human knowledge.

Note that despite the Heisenberg principle, quantum mechanical measurements are not always uncertain. When a system is measured (prepared) in an eigenstate, a subsequent measurement (Pauli's measurement of the first kind) will find it in the same state with perfect certainty.

What are the normal possibilities for new quantum states? The transformation theory of Paul Dirac and Pascual Jordan lets us represent ψ in a set of basis functions for which the combination of quantum systems (one may be a measurement apparatus) has eigenvalues (the *axiom of measurement*). We represent ψ as in a linear combination (the *principle of superposition*) of those "possible" eigenfunctions. Quantum mechanics lets us calculate the probabilities of each of those "possibilities."

Interaction with the measurement apparatus (or indeed interaction with any other system) may select out (the *axiom of measurement*) one of those possibilities as an actuality. But for this event to be an "observable" (a John Bell "beable"), information must be created and positive entropy must be transferred away from the new information structure, in accordance with our two-step information creation process.

All interpretations of quantum mechanics predict the same experimental results. The information interpretation is no exception, because the experimental data from quantum experiments is the most accurate in the history of science.

Where interpretations differ is in the picture (the *visualization*) they provide of what is "really" going on in the microscopic world - so-called "quantum reality." Schrödinger called it *Anschaulichkeit*. He and Einstein were right that we should be able to picture quantum reality.

However, the Copenhagen interpretation of Niels Bohr and Werner Heisenberg discourages attempts to visualize the nature of the "quantum world," because they say that all our experience is derived from the "classical world" and should be described in ordinary language. This is why Bohr and Heisenberg insisted on some kind of "cut" between the quantum event and the mind of an observer.

The information interpretation encourages visualization. (See our on-line animation of the two-slit experiment[2], our EPR experiment visualizations[3], and Dirac's three polarizers[4] to visualize the superposition of states and the projection or "collapse" of a wave function.)

Bohr was of course right that classical physics plays an essential role. His Correspondence Principle allowed him to recover some important physical constants by assuming that the discontinuous quantum jumps for low quantum numbers (low "orbits" in his old quantum theory model) converged in the limit of large quantum numbers to the continuous radiation emission and absorption of classical electromagnetic theory.

In addition, we know that in macroscopic bodies with enormous numbers of quantum particles, quantum effects are averaged over, so that the uncertainty in position and momentum of a large body still obeys Heisenberg's indeterminacy principle, but the uncertainty is for all practical purposes unmeasurable and the body can be treated classically.

We can say that the quantum description of matter also converges to a classical description in the limit of large numbers of quantum particles. We call this "adequate" or statistical determinism. It is the apparent determinism we find behind Newton's laws of motion for macroscopic objects. The statistics of averaging over many independent quantum events then produces the "quantum to classical transition" for the same reason as the "law of large numbers" in probability theory.

Both Bohr and Heisenberg suggested that just as relativistic effects can be ignored when the velocity is small compared to the velocity of light ($v / c \rightarrow 0$), so quantum effects might be ignorable when Planck's quantum of action $h \rightarrow 0$. But this is quite wrong,

2 .informationphilosopher.com/solutions/experiments/two-slit_experiment/
3 informationphilosopher.com/solutions/experiments/EPR/
4 www.informationphilosopher.com/solutions/experiments/dirac_3-polarizers/

because h is a constant that never goes to zero. In the information interpretation, it is always a quantum world. As we saw, the conditions needed for ignoring quantum indeterminacy are when the mass of the macroscopic "classical" object is large.

Note that the macromolecules of biology are large enough to stabilize their information structures. DNA has been replicating its essential information for billions of years, resisting equilibrium despite the second law of thermodynamics The creation of irreversible new information also marks the transition between the quantum world and the "adequately deterministic" classical world, because the information structure itself must be large enough (and stable enough) to be seen. The typical measurement apparatus is macroscopic, so the quantum of action h becomes small compared to the mass m and h / m approaches zero.

Decoherence theorists say that the measurement problem is our failure to see quantum superpositions in the macroscopic world. The information interpretation thus explains why quantum superpositions like Schrödinger's Cat are not seen in the macroscopic world. Stable new information structures in the dying cat reduce the quantum possibilities (and their potential interference effects) to a classical actuality. Upon opening the box and finding a dead cat, an autopsy will reveal that the time of death was observed/recorded. The cat is its own observer.

The "Possibilities Function"

The central element in quantum physics is the "wave function" ψ, with its mysterious wave-particle dual nature (sometimes a wave, sometimes a particle, etc.). We believe that teaching and understanding quantum mechanics would be much simpler if we called ψ the "possibilities function." It only looks like a wave in simple cases of low-dimensional coordinate space. But it always tells us the possibilities - the possible values of any observable, for example.

Given the "possibilities function" ψ, quantum mechanics allows us to calculate the "probabilities" for each of the "possibilities." The calculation depends on the free choice of the experimenter as to which "observables" to look for. If the measurement apparatus can register n discrete values, ψ can be expanded in terms of a set of basis functions (eigenfunctions) appropriate for the chosen observable, say φ_n. The expansion is

$$\psi = \Sigma\, c_n\, \varphi_n$$

When the absolute squares of the coefficients c_n are appropriately normalized to add up to *1*, the probability P_n of observing an eigenvalue n is

$$P_n = |\, c_n\,|^2 = |\, < \psi \,|\, \varphi_n > |^{\,2}$$

These probabilities are confirmed statistically by repeated identical experiments that collect large numbers of results. Quantum mechanics is the most accurate physical theory in science, with measurements accurate to fifteen decimal places.

In each individual experiment, generally just one of the possibilities becomes an actuality (although some experiments leave the quantum system in a new superposition of multiple possibilities).

In our information interpretation, a possibility is realized or actualized at the moment when information is created about the new state of the system. This new information requires that positive entropy be carried away from the local increase in negative entropy.

Note that an "observer" will not be able to make a "measurement" unless new information exists to be "observed." Information must be (and is in all modern experimental systems) created and recorded *before any observer looks at the results*. Measurements do not depend directly on the mind of the observer, only indirectly when the observer sets up the experimental apparatus and decides (chooses freely) what the apparatus will measure.

This is called the "free choice" of the experimenter.[5]

An information approach can help philosophers to think more clearly about quantum physics. Instead of getting trapped in talk about mysterious "collapse of the wave function," "reduction of the wave packet," or the "projection postulate" (all important issues), the information interpretation proposes we simply say that one of the "possibilities" has become "actual."

5 informationphilosopher.com/freedom/free_choice.html

It is intuitively obvious that when one possibility becomes actual, all the others are annihilated, consigned to "nothingness," as Jean-Paul Sartre put it. And because the other possibilities may have been extremely "distant" from the point of actualization, their instantaneous disappearances looked to Einstein to violate his new principle of relativity, but they do not.

Quantum theory lets us put quantitative values on the "probabilities" for each of the "possibilities." But this means that quantum theory is fundamentally statistical, meaning indeterministic and "random." It is not a question of our being ignorant about what is going on (an epistemological problem). What's happening is ontological chance, as Einstein first showed, but as he forever disliked.

We can describe the "possibilities function" ψ as moving through space (at the speed of light, or even faster, as Einstein feared?), exploring all the possibilities for wherever the particle might be found. This too may be seen as a special kind of information. In the famous "two-slit experiment[6]," the "possibilities function" travels everywhere, meaning that ψ passes through both slits, interfering with itself and thus changing the possibilities where the particle might be found. Metaphorically, ψ "knows" when both slits are open, even if our intuitive classical view imagines that the particle must go through only one. The slits being open changes the probabilities associated with each of the possibilities.

Possibilities and Information Theory

It is of the deepest philosophical significance that information theory is based on the mathematics of probability. If all outcomes were certain, there would be no "surprises" in the universe. Information would be conserved and a universal constant, as some mathematicians mistakenly believe. Information philosophy requires the ontological uncertainty and probabilistic outcomes of modern quantum physics to produce new information.

6 informationphilosopher.com/solutions/experiments/two-slit_experiment/

In Claude Shannon's theory of the communication of information, there must be multiple possible messages in order for information to be communicated. If there is only one possible message, there is no uncertainty, and no information can be communicated.

In a universe describable by the classical Newtonian laws of motion, all the information needed to produce the next moment is contained in the positions, motions, and forces on the material particles.

In a quantum world describable by the unitary evolution of the deterministic Schrödinger equation, nothing new ever happens, there is no new "outcome." Outcomes are added to standard quantum mechanics by the addition of the "projection postulate" or "collapse of the wave function," when the quantum system interacts with another system.

Information is constant in a deterministic universe. There is "nothing new under the sun." The creation of new information is not possible without the random chance and uncertainty of quantum mechanics, plus the extraordinary temporal stability of quantum mechanical structures needed to store information once it is created.

Without the extraordinary stability of quantized information structures over cosmological time scales, life and the universe we know would not be possible. That stability is the consequence of an underlying digital nature. Quantum mechanics reveals the architecture of the universe to be discrete rather than continuous, to be digital rather than analog. Digital information transfers are essentially perfect, whereas analog transfers are "lossy."

It is Bohr's "correspondence principle" of quantum mechanics for large quantum numbers and the "law of large numbers" of statistics which ensure that macroscopic objects can normally average out microscopic uncertainties and probabilities to provide the statistical or "adequate" determinism that shows up in all our classical "laws of nature."

There is no separate classical world and no need for a quantum-to-classical transition. The quantum world becomes statistically deterministic when the mass of an object is such that h / m approaches zero. We conclude, contrary to the views of Bohr and Heisenberg, that there is no need for a separate classical world. The classical laws of nature emerge statistically from quantum laws. Quantum laws, which are therefore universally applicable, converge in these two limits of large numbers to classical laws. There is no "transition" from the quantum world to a separate classical world. There is just one world, where quantum physics applies universally, but its mysterious properties, like interference, entanglement, and nonlocality, are normally invisible, averaged over, in the macroscopic world.

The problem for an informational interpretation of quantum mechanics is to explain exactly how these two convergences (large numbers of particles and large quantum numbers) allow continuous and apparently deterministic macroscopic information structures to emerge from the indeterministic and discontinuous microscopic quantum world.

We show how the determinism in the macroscopic world is only a *statistical* or adequate determinism, the result of "averaging over" the large number of independent quantum events happening in a macroscopic object. And even more important, we must show how the occasional magnification or amplification of microscopic quantum events leads to new macroscopic information that makes human beings the "authors of their lives", that makes them "co-creators of our universe," and that guarantees a genuinely open future with alternative possibilities, not in inaccessible "parallel universes" but in the one universe that we have.

Other Interpretations of Quantum Mechanics

Standard "orthodox" interpretations of quantum mechanics include the *projection postulate*, the "collapse of the wave function."

Today there appear to be about as many unorthodox interpretations that deny the collapse, as there are more standard views. We characterize each interpretation as deterministic or not, local or non-local reality, if they assume hidden variables, need a conscious observer, and accept particles. Their proponents are in parentheses..

No-Collapse Interpretations

Statistical Ensemble - indeterministic, non-local, no observer - (Einstein-Born- Ballentine)

Pilot-Wave Theory - deterministic, non-local, hidden variables, no observer, particles - (de Broglie-Bohm, 1952)

Many-Worlds - deterministic, local, hidden variables, no observer - (Everett-DeWitt, 1957)

Time-Symmetric Theory - (Aharanov, 1964)

Decoherence - deterministic, local, no particles - (Zeh-Zurek, 1970)

Modal Interpretation - (van Frassen, 1972)

Consistent Histories - local - (Griffith-Omnès-Gell-Mann-Hartle, 1984)

Collapse Interpretations

Copenhagen Interpretation - indeterministic, non-local, observer - (Bohr-Heisenberg-Born-Jordan, 1927)

Conscious Observer - indeterministic, non-local, observer - (Von Neumann-Wigner)

Objective Collapse - indeterministic, non-local, no observer - (Ghirardi-Rimini-Weber, 1986; Penrose, 1989)

Transactional Interpretation - indeterministic, non-local, no observer, no particles - (Cramer, 1986)

Relational Interpretation - local, observer - (Rovelli, 1994)

Pondicherry Interpretation - indeterministic, non-local, no observer - (Mohrhoff, 2005)

Information Interpretation - Our interpretation is statistical, indeterministic, non-local, and no observer is needed. It interprets the "collapse" of the "possibilities" function according to Dirac's "*projection postulate*."[7] New is the requirement for the physical recording of information before any "observation" can be made.

7 See chapter 20.