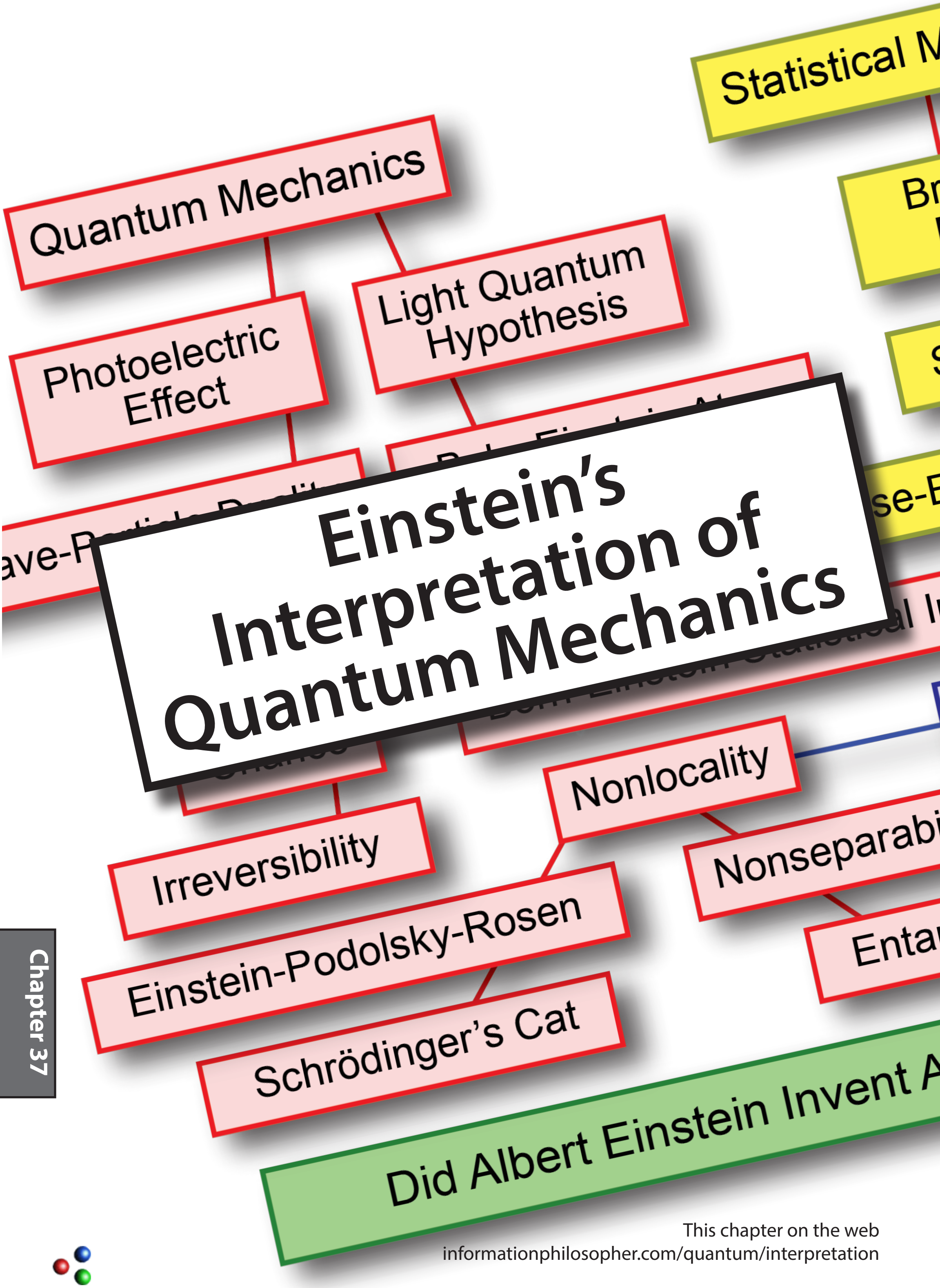
Einstein's Interpretation of Quantum Mechanics



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Einstein's Interpretation of Quantum Mechanics

Einstein's main objection to the Copenhagen Interpretation of quantum mechanics was its claim that a particle has no position, or indeed any other observable property, until the particle is measured. He famously told the philosopher Hilary Putnam "Look, I don't believe that when I am not in my bedroom my bed spreads out all over the room, and whenever I open the door and come in it jumps into the corner."

Despite his reputation as the major critic of quantum mechanics, Einstein came to accept its indeterminism and statistical nature. As we have seen, he had himself discovered these aspects of quantum mechanics. If it is merely *constructed* on data derived from experience, quantum mechanics can only be approximate.

Einstein always hoped to discover - or invent - a more fundamental theory, preferably a field theory like the work of Newton and Maxwell and his own relativity theories. He dreamed of a single theory that would unite the gravitational field, the electromagnetic field, the "spinor field," and even what he called the "ghost field" or "guiding field" of quantum mechanics.

Such a theory would use partial differential equations that predict field values continuously for all space and time. That theory would be a free invention of the human mind. Pure thought, he said, could comprehend the real, as the ancients dreamed.[1]

Einstein wanted a field theory based on absolute principles such as the constant velocity of light, the conservation laws for energy and momentum, Ehrenfest's adiabatic principle, or Boltzmann's principle that the entropy of a system depends on the possible distributions of its components.

We can now see the elements of Einstein's interpretation, because fields are not substantial, like particles. They are abstract immaterial *information* that predicts the behavior of a particle at a given point in space and time, should one be there!

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[1] On The Method of Theoretical Physics, p.167

Fields are *information*. Particles are *information structures*.

A gravitational field describes paths in curved space that moving particles follow. An electromagnetic field describes the forces felt by an electric charge at each point. The wave function Ψ of quantum mechanics - we can think of it as a possibility field - provides probabilities that a particle will be found at a given point.

In all three cases continuous immaterial information describes causal influences over discrete material objects.

Note that the local values of all these fields depend on the distribution of matter in the rest of space, the so-called "boundary conditions." Curvature of space depends on the distribution of masses. Electric fields depend on the distribution of charges. And quantum possibility fields depend on whether there are one or two slits open in the famous and mysterious experiment.

The quantum possibility field, calculated from the deterministically evolving Schrödinger equation, is a property of space. Like all fields, it exists whether or not there is a particle present.

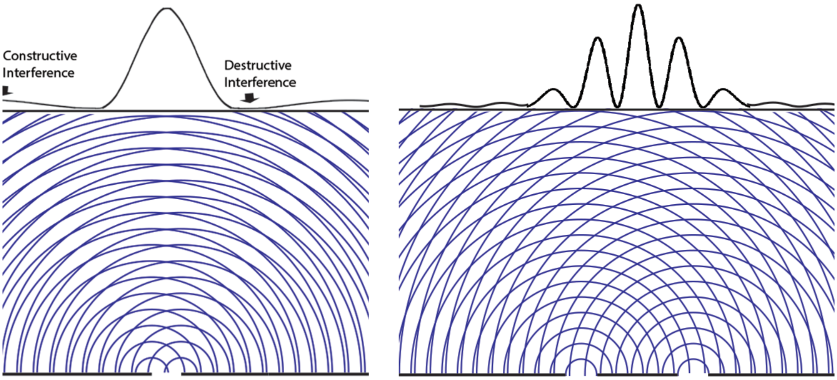

Figure 1-5. Experiments with one-slit and two-slits open, showing the possibilities field calculated from $|\psi|^2$. The possibilities field for two slits open applies whichever slit the particle enters. It is a property of the boundary conditions for the space.

We can now summarize Einstein's thinking about field theories, resulting in a new interpretation of quantum mechanics.

Einstein's Thoughts About Quantum Mechanics

1. Individual particles have the usual classical properties, like position and momentum, plus uniquely quantum properties, like spin, but these properties can only be established statistically. The quantum theory gives us statistical information about an individual particle position, the probable values of its possible properties. A particle like an electron is a compact information structure with a definite position and momentum, even if it is unknown.

2. The quantum wave functions are *fields*. Einstein called them ghost fields or guiding fields. The fields are *not* the particles. The fields have values in many places at the same time. Quantum field values are complex numbers which allow interference effects, causing some places to have no particles. Fields are not localized. Einstein showed that a particle of matter or energy is always localized. Light quanta are emitted and absorbed only as units, for example when one ejects an electron in the photoelectric effect.

3. Because quantum physics does not give us precise information about a particle's location, it is *incomplete* when compared to classical physics. Quantum mechanics is a statistical theory and contains only probable information about an individual particle.

4. The Copenhagen notion of *complementarity*, that a quantum object is both a particle and a wave, or sometimes one and sometimes the other, depending on the measurements performed, is confusing and simply wrong. A particle is always a particle and the wave behavior of its probability field is simply one of the particle's properties, like its mass, charge, spin, etc.

5. While the probability wave field is abstract and immaterial information, it *causally* influences the matter or energy, just as the particle's spin dramatically alters its statistical properties, as Einstein showed in 1924. These nonintuitive behaviors are simply impossible in classical physics.

6. Although Niels Bohr deserves credit for arranging atoms in the periodic table, the deep reasons for two particles in the first

shell and eight in the second were only clear after Einstein discovered spin statistics in 1924, following a suggestion by S. N. Bose.

7. In the two-slit experiment, Einstein's localized particle *always goes through one slit or the other*, but when the two slits are open the probability wave function, which influences where the particle can land, is different from the wave function when one slit is open. The possibilities field (a wave) is determined by the boundary conditions of the experiment, which are different when only one slit is open. The particle does not go through both slits, It does not "interfere with itself." It is not in two places at the same time.

8. In the experiment with two entangled particles, introduced by Einstein in the 1935 EPR paradox paper, the Copenhagen assumption that each particle is in a random unknown combination of spin up and spin down, independent of the other particle, simply because we have not yet measured either particle, is the source of the paradox. Just as a particle has an unknown bur definite position, entangled particles have definite spins, even if they are unknown individually, they are interdependent jointly.

When the particles travel away from the central source, with total spin zero, one is at all times spin up, the other is spin down. The operative principle for Einstein is conservation of spin. To assume that their spins are independent is to consider the absurd outcome that spins could be found both up (or down), a violation of a conservation principle that is much more egregious than the amazing fact spins are always perfectly correlated in any measurements.

9. Erwin Schródinger explained to Einstein in 1936 that two entangled particles share a single wave function that can not be separated into the product of two single-particle wave functions, at least not until there is an interaction with another system that *decoheres* their perfect correlation.

10. Einstein ultimately accepted the indeterminism in quantum mechanics and the uncertainty in conjugate variables, despite the clumsy attempt by his colleagues Podolsky and Rosen to challenge uncertainty and restore determinism in the EPR paper.

11. In 1931 Einstein called P.A.M.Dirac's transformation theory "the most perfect exposition, logically, of this [quantum] theory"

even though it lacks "enough information to enable one to decide" a particle's exact properties.[2] In 1933 Dirac reformulated quantum physics using a Lagrangian rather than the standard Hamiltonian representation. The time integral of the Lagrangian has the dimensions of action, the same as Planck's quantum of action *h*. And the *principle of least action* visualizes the solution of dynamical equations like Hamilton's as exploring all paths to find that path with minimum action.

Dirac's work led RICHARD FEYNMAN to invent the path-integral formulation of quantum mechanics. The transactional interpretations of JOHN CRAMER and RUTH KASTNER have a similar view. The basic idea of exploring all paths is in many ways equivalent to saying that the probabilities of various paths are determined by a solution of the wave equation using the boundary conditions of the experiment. As we saw above, such solutions involve whether one or two slits are open, leading directly to the predicted interference patterns, given only the wavelength of the particle.

12. In the end, of course, Einstein held out for a continuous field theory, one that could not be established on the basis of any number of empirical facts about measuring particles, but must be based on the discovery of principles, logically simple mathematical conditions which determine the field with differntial equations. His lifelong dream was a "unified field theory," one that at least combined the gravitational field and electromagnetic field, and one that might provede an underpinning for quantum mechanics someday.

Einstein was clear that even if his unified field theory was to be deterministic and causal, the statistical indeterminism of quantum mechanics itself would have to be preserved.

This seemingly impossible requirement is easily met if we confine the determinism to Einstein's continuous field theories, which are pure abstract immaterial information. Einstein's discovery of indeterminism and the statistical nature of physics we apply only to particles, which are information structures.

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[2] *Ideas and Opinions*, p. 270

Information Philosophy and Einstein's Interpretation

I-Phi offers a visualization of what is going on in quantum reality, with animations (on-line[3]) of the wave function evolution and the appearance of the particle, when the wave function "collapses" and the possibilities field shrinks to its minimum possible size h^3.

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.

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, and only then, become knowledge recorded in the observer's mind.

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 similarly only statistically determined.

- There is only one world.
- It is a quantum world.

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

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

It is an error to compare *h* going to zero in quantum mechanics with *v* being small compared to *c* in relativity theory. Velocity *v* can go to zero. Planck's quantum of action *h* can not.

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[3] informationphilosopher.com/quantum/collapse/

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 to certainty.

Information philosophy interprets the wave function ψ as a "possibilities" field. With this simple change in terminology, the mysterious process of a wave function "collapsing" becomes a much more intuitive discussion of ψ providing all the possibilities (with mathematically calculable probabilities), followed by a single actuality, at which time the probabilities for all non-actualized possibilities go to zero (they "collapse") instantaneously. But no matter, no energy, and in particular, no information is transferred anywhere!

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 interpretations of quantum mechanics deny).

But 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 explores.

Information is not a conserved quantity like energy and mass, despite the view of many mathematical physicists, who generally accept determinism. 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, motions, and force 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 (chapter 22) as its own observer.

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 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 Dirac and 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. An 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 Neils 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.

Copenhageners were proud of their limited ability to know. Bohr actually claimed...:

> There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature.

The information interpretation encourages visualization. (See our on-line animation of the two-slit experiment[4], our EPR experi-

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[4] .informationphilosopher.com/solutions/experiments/two-slit_experiment/

ment visualizations[5], and Dirac's three polarizers[6] 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, because h is a constant that never goes to zero. In the information interpretation, it is always a quantum world. The conditions needed for ignoring quantum indeterminacy are when the mass of the macroscopic "classical" object is large.

Noting that the momentum p is the product of mass and velocity mv, Heisenberg's indeterminacy principle, $\Delta p \, \Delta x > h$, can be rewritten as $\Delta v \, \Delta x > h / m$. It is thus not when h is small, but when h / m is

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[5] informationphilosopher.com/solutions/experiments/EPR/

[6] www.informationphilosopher.com/solutions/experiments/dirac_3-polarizers/

small enough, that errors in the position and momentum of macroscopic objects become smaller that can be measured.

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 our failure to see quantum superpositions in the macroscopic world *is* the measurement problem 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.