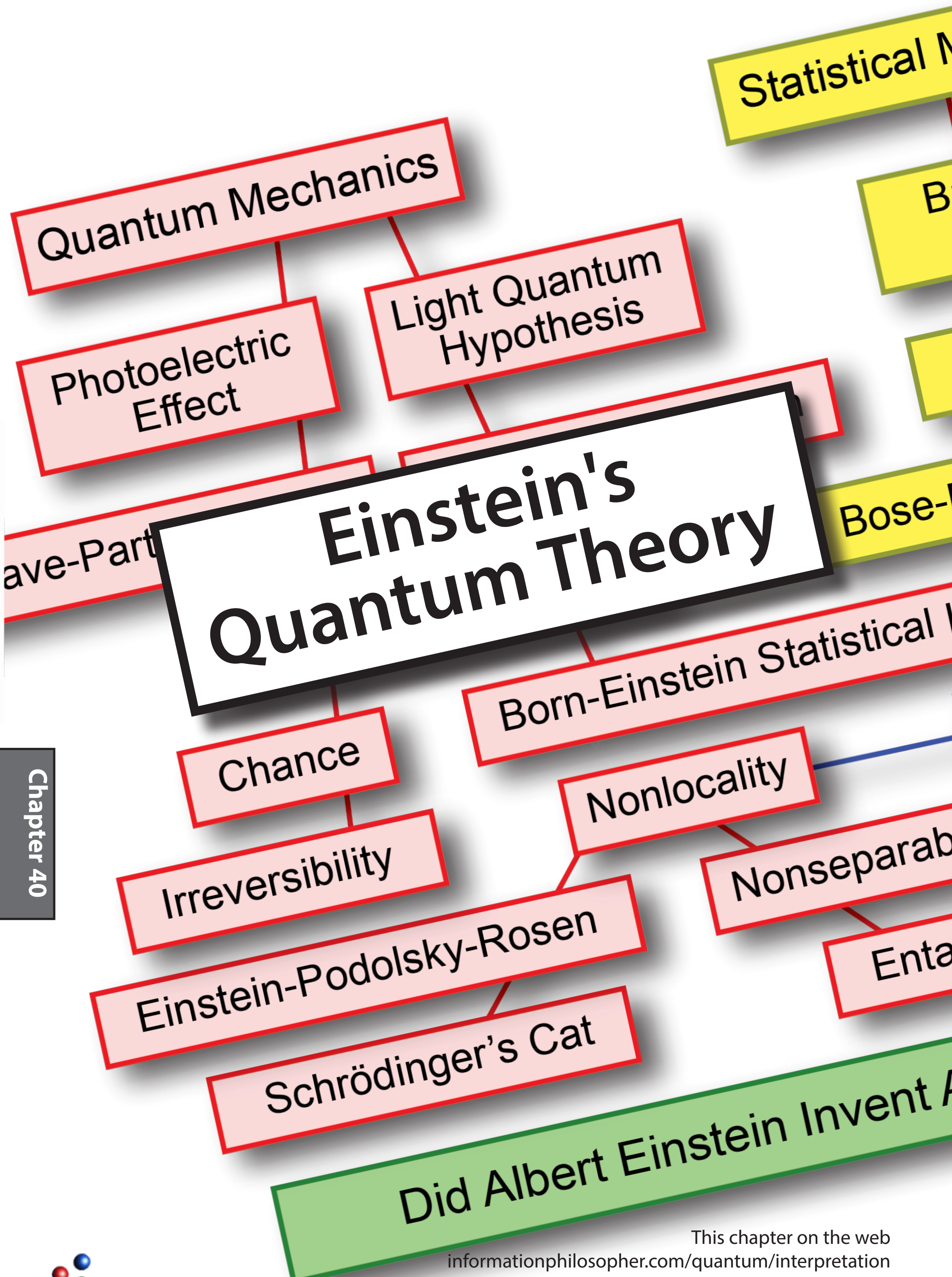

Chapter 40

This chapter on the web
informationphilosopher.com/quantum/interpretation

Einstein's Quantum Theory

We have noted Einstein's view that *principles* are the best basis for scientific theories (chapter 35?) and that quantum mechanics is fundamentally a *statistical* theory - despite Einstein's doubts about the reality of chance (chapter 36?),. We have also elaborated Einstein's suspicions about the continuum (chapter 37?) and his concerns about continuous field theories (chapter 38?).

We now propose to examine a quantum theory that would embrace Einstein's hope for an "objective reality" underlying quantum mechanics. The only "real "elements will be the particles.

We also suggest that the quantum wave function might be considered a continuous "field" that can be put alongside the gravitational and electromagnetic fields, not in a single "unified field theory" as Einstein hoped, but as a field nevertheless and with mind-boggling power over the particles.

Continuous fields of gravitation and of electromagnetism allow us to calculate precisely the forces on a test particle at a geometric point, should a particle be there. The quantum wave function is also a continuous field. It describes the probability of finding a particle at a given point in continuous space and time. All these continuous fields are determined for all space and time by the distribution of particulate matter and energy in space, the so-called boundary conditions and initial conditions.

Just as general relativity can be seen as curving space, so quantum theory can be seen to add a property to space that “influences” the discrete particles. In Richard Feynman’s path-integral formulation of quantum mechanics, the principle of least action explores all space to establish the quantum probabilities everywhere.

But infinities arise when we represent space and time with a continuum We imagine an infinite number of infinitesimal points between any two points on a line. Long before Einstein, Ludwig Boltzmann had his doubts about the continuum and its infinities.

Should space and time be merely "free creations of the human mind," should they not "exist" in the same sense that matter and energy particles exist, and should they be only ideal and not "real", then the implications for quantum theory are profound.

If the "objectively real" (chapter 39) includes only material and energy particles obeying the most established laws of physics such as the conservation laws and the principles of symmetry behind them, we must reassess quantum theory, and we must follow Einstein's extraordinary insights wherever they lead, despite his well-known doubts about violations of his relativity.

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. This is mostly anthropomorphic nonsense

His second objection was taking the superposition of states to describe "objectively real" superpositions, so that particles can be in two places at the same time.

Einstein's idea is that there is an "objective reality" in nature where particles have definite positions and paths, definite energies, momenta, and spins, even if quantum mechanics limits our ability to know them with the perfect precision of classical mechanics.

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 (chapters 6, 11, and 12).

If the theory were merely *constructed* on data derived from experience, he said, quantum mechanics can only be approximate.

He wanted a better theory based on principles.

Einstein always hoped to discover - or better 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 to predict field values continuously for all space and time. That theory would be a "free creation of the human mind." Pure thought, he said, mere ideas, 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, symmetry principles, and Boltzmann's principle that the entropy of a system depends on the possible distributions of its components among the available phase-space cells.

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

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 possibilities field - provides probabilities that a particle will be found at a given point.

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

In chapter 39, we showed that Einstein's insights about an "objective reality" can explain

1) nonlocality, which appears to violate his principle of relativity,

2) the two-slit experiment, which RICHARD FEYNMAN described as the "one mystery" of quantum physics,

3) entanglement, which ERWIN SCHRÖDINGER thought was "the characteristic trait" of quantum mechanics,

and 4) Ludwig Boltzmann's "molecular disorder," the origin of macroscopic irreversibility in thermodynamics..

Einstein's work also illuminates a few other quantum puzzles such as wave-particle duality, the metaphysical question of ontological chance, the "collapse" of the wave function, the "problem of measurement," the role of a "conscious observer," the conflict between relativity and quantum mechanics, and even the puzzle of Schrödinger's Cat.

Let's see how Einstein can help us understand these quantum puzzles and mysteries.

1 On The Method of Theoretical Physics, p.167

Einstein's "Objectively Real" Quantum Mechanics

Note that the local values of any field depends 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 and magnetic fields depend on the distribution of charges. And a quantum probability field depends on whether there are one or two slits open in the mysterious two-slit experiment. No particle has to travel through both slits in order for interference fringes to appear.

The quantum probability field $|\Psi|^2$, calculated from the deterministic Schrödinger equation, is a property of space. Like all fields, it has a value at each point whether or not there is a particle present there. Like all fields, it is determined by the distribution of nearby matter in space. These are the boundary conditions for the field. It has continuous values at every point, whether or not any particle is present at a given point.

1. Individual particles have the usual classical properties, like position and momentum, plus uniquely quantum properties, like spin, but all these properties can only be established *statistically*. The quantum theory gives us only statistical information about an individual particle's position and momentum, consistent with Werner Heisenberg's uncertainty principle, and only probable values for all possible properties.

But "objectively," a particle like an electron is a compact information structure with a definite, albeit unknown, position and momentum, both of which cannot be measured together with arbitrary accuracy. And it has other definite properties, such as the spatial components of electron spin, or of photon polarization, which also can not be measured together.

Just because we cannot measure an individual particle path with accuracy does not mean the particle does not follow a continuous path, let alone be in two places at the same time. And along this path, Einstein's "objective reality" requires that all the particle's properties are conserved, as long as there is no interaction with the external environment.

What is at two (or more) places at one time is the quantum wave function ψ, whose squared modulus $|\psi|^2$ gives us the non-zero probability of finding the particle at many places. But the matter/energy particle is not identical to the *immaterial* wave function!

Einstein and Schrödinger were strongly critical of the Copenhagen Interpretation's implication that superpositions represent real things. Tongue in cheek, Einstein suggested a superposition of explosives that would both explode and not explode. Schrödinger turned Einstein's criticism into a cat that is in a superposition of dead and alive.

It is testimony to the weirdness in modern quantum theory that Schrödinger's Cat is today one of the most popular ideas in quantum mechanics, rarely seen as a trenchant criticism of the theory.

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

Einstein was the first physicist to see wave-particle duality. And he was first to interpret the wave as the probability of finding a particle. Max Born's identification of the probability as the squared modulus $|\psi|^2$ of the wave function only made Einstein's qualitative identification quantitative and calculable.

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. Just as the gravitational field gives us the gravitational force on the particle, $|\Psi|^2$ gives us the probability of finding the particle at every point.

For Einstein, attempts to describe quantum objects as *nothing but* waves was absurd.

3. Because quantum physics does not give us precise information about a particle's location, Einstein was right to call it *incomplete, especially* when compared to classical physics. Quantum mechanics is a *statistical* theory and contains only probable information about an individual particle. Einstein's example of incompleteness was very simple. If we have one particle in two possible boxes, an *incomplete* theory gives us the probabilities of being found in each box. A *complete* theory would say for example, "the particle is in the first box."

4. While the probability wave field is abstract and *immaterial* information (Einstein's "ghost field") it *causally* influences the particle (Einstein's "guiding field"), just as the particle's spin dramatically alters its quantum statistics, another Einstein discovery. In particular. ψ somehow controls a particle's allowed positions though not by exerting any known forces. These non-intuitive behaviors are simply impossible in classical physics, and the empirical evidence for them is only seen (statistically) in large numbers of experiments, never in a single experiment.

In Einstein's quantum theory, there is no evidence that a single particle ever violates conservation principles by changing its position or any other property discontinuously. Changes in a particle's properties are always the results of interacting with other particles.

5. 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 only became clear after Einstein discovered spin statistics in 1924, following a suggestion by S. N. Bose, and after Paul Dirac and Enrico Fermi extended the work to electrons. .

6. 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 be, 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 *never in two places at the same time*.

This agrees with Bohmian mechanics, which says that the wave function goes through both slits, even as the particle "objectively"always goes through only one slit.

7. The experiment with *two* entangled particles was 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 wrong and the source of the EPR "paradox." Just as a particle has an unknown but definite position, entangled particles have definite spins, conserved since their initial preparation, even if the spins are unknown individually, they are interdependent jointly to conserve total spin.

When the particles travel away from the central source, with total spin zero, the two spins are opposite at all times. Or at a minimum, the spin is undefined for each particle because it is rotationally invariant and isotropic the same in all directions. When Alice chooses an angle to measure the spin, she adds new information that was not present at the original entanglement.

One operative principle for Einstein's "objective reality" is conservation. To assume that their spins are independent is to consider the absurd outcome that spins could be found both up (or both down), a violation of a conservation principle that is more egregious than the amazing fact spins are always perfectly correlated in any measurements.

8. Erwin Schrödinger 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 which *decoheres* their perfect correlation. This is intuitively understandable because conservation laws preserve their perfect correlation unless one particle is disturbed, for example by environmental decoherence, by some interaction with the environment.

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

10. In 1931 Einstein called 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.

11. 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 differential equations. His dream was a "unified field theory," one that at least combined the gravitational field and electromagnetic field, and one that might provide 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 in Einstein's "objectively real" quantum theory if we confine determinism to Einstein's *continuous* fields, which are pure abstract immaterial information. Einstein's 1917 discovery of indeterminism and the

2 *Ideas and Opinions*, p. 270

statistical nature of physics need apply only to particles, which are *discrete* information structures.

It is therefore most significant to note that the mathematics of Schrödinger's wave equation and his wave function is entirely deterministic.

Quantum systems are often pictured as evolving in two ways, thought to be logically inconsistent by many physicists and philosophers:

• The first is the continuous wave function deterministically exploring all the possibilities for interaction (cf. von Neumann process 2).

• The second is the particle randomly choosing one of those possibilities to become actual (cf. von Neumann process 1).

No knowledge can be gained by a "conscious observer" unless new information has previously been irreversibly recorded in the universe. Such 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. See John Bell's "shifty split" in chapter 32.

The measuring apparatus is material and quantum mechanical, not deterministic or "classical." It need only be statistically determined and capable of recording the *irreversible* information about an interaction. The apparatus is on the "classical" side of the "quantum to classical transition." 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.

$\Delta v\ \Delta x \geq h / m$ becomes immeasurably small as *m* increases and 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* is constant so it cannot.

The classical laws of motion, with their apparently 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!

Einstein's "objectively real" quantum theory is standard quantum physics, though freed of some absurd Copenhagen Interpretations. It accepts the Schrödinger equation of motion, Dirac's *principle of superposition*, his *axiom of measurement* (now including the actual information "bits" measured), and - most importantly - Dirac's *projection postulate*, the "collapse" of ψ that so many interpretations of quantum mechanics deny.

And Einstein's quantum theory does not need the "conscious observer" of the Copenhagen Interpretation thought to be required for a projection, for the wave-function to "collapse," for one of the possibilities to become an actuality. All the collapse does require is an interaction between systems that creates irreversible and observable, but not necessarily observed, information.

Einstein's quantum theory denies that particles have no properties until measurements are made by these "conscious observers.

Among the founders of quantum mechanics, almost everyone agreed that irreversibility is a key requirement for a measurement. As Einstein appreciated, irreversibility introduces statistical mechanics and thermodynamics into a proper formulation of quantum mechanics.

Information is not a conserved quantity like energy and mass, despite the view of many mathematical physicists, who generally accept the determinist idea that information too is conserved.

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 are thought to be deterministic so that the information in any configuration of bodies, motions, and force is enough to know all past and future configurations (Laplace's intelligent demon). Classical mechanics does, in principle, conserve 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 also 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!

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. We'll discuss it further briefly in chapter 41.

Note that despite the Heisenberg uncertainty 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 *projection postulate*) 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. Einstein's "objectively real" quantum theory 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 Bohr and Heisenberg discourages all 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 what is going on in "quantum reality." 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.

Einstein's "objective reality" is based on things we can visualize, without being able to measure them directly. (See our on-line animation of the two-slit experiment[3], our EPR experiment visualizations[4], and Dirac's three polarizers[5] to visualize the superposition of states and the projection or "collapse" of a wave function.)

Einstein and Schrödinger made fun of superposition, but Einstein never doubted the validity of any of Dirac's "principles" of quantum mechanics. What Einstein attacked was the nonsense of assuming that real objects could be in such a superposition, both here and there, both dead and alive. etc.

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

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

independent quantum events then produces the "quantum to classical transition" for the same reason as the "law of large numbers" in probability theory approaches a continuous function..

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. Biological entities are 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 Einstein's "objective reality" 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 nadir of interpretation was probably the most famous interpretation of all, the one developed in Copenhagen, the one Niels Bohr's assistant Leon Rosenfeld said was not an interpretation at all, but simply the "standard orthodox theory" of quantum mechanics.

It was the nadir of interpretation because Copenhagen wanted to put a stop to "interpretation" in the sense of understanding or "visualizing" an underlying reality. The Copenhageners said we should not try to "visualize" what is going on behind the collection of observable experimental data. Just as Kant said we could never know anything about the "thing in itself," the *Ding-an-sich*, so the positivist philosophy of Auguste Comte, Ernst Mach, Bertrand Russell, Rudolf Carnap, as well as the British empiricist thinkers John Locke and David Hume, claim that knowledge stops at the "secondary" sense data or perceptions of phenomena, preventing access to the primary "objects."

Einstein's views on quantum mechanics have been seriously distorted (and his early work largely forgotten), perhaps because of his famous criticisms.

Though its foremost critic, Einstein frequently said that quantum mechanics was a most successful theory, the very best theory so far at explaining microscopic phenomena, but that he hoped his ideas for a continuous field theory would someday add to the discrete particle theory and its "nonlocal" phenomena. It would allow us to get a deeper understanding of underlying reality, though at the end he despaired any his continuous field theory compared to particle theories.

Many if not most of the "interpretations" of quantum mechanics deny a central element of quantum theory, one that Einstein himself established in 1916, namely the role of indeterminism, or "chance," to use its traditional name, as Einstein did in physics (in German, *Zufall*) and as William James did in philosophy in the 1880's. These interpretations all hope to restore the determinism of classical mechanics.

Many interpretations even deny the existence of particles. They admit only waves that evolve unitarily under the Schrōdinger equation.. They like to regard the wave function as a real entity rather than an abstract possibilities function.

We can therefore classify various interpretations by whether they accept or deny chance, especially in the form of the so-called "collapse" of the wave function, also known as the "reduction" of the wave packet or what Paul Dirac called the "projection postulate." Most "no-collapse" theories are deterministic. "Collapses" in standard quantum mechanics are irreducibly indeterministic.

Einstein's criticisms of quantum mechanics, in the form of many attempts to visualize what is going on in "quantum reality," led him to make many mistakes, as we shall see in chapter 42

But behind almost every Einstein "mistake" was an extraordinary insight that has led to some of today's most fascinating and puzzling aspects of quantum mechanics. Einstein's "objective reality" is our best hope for resolving some of those puzzles.