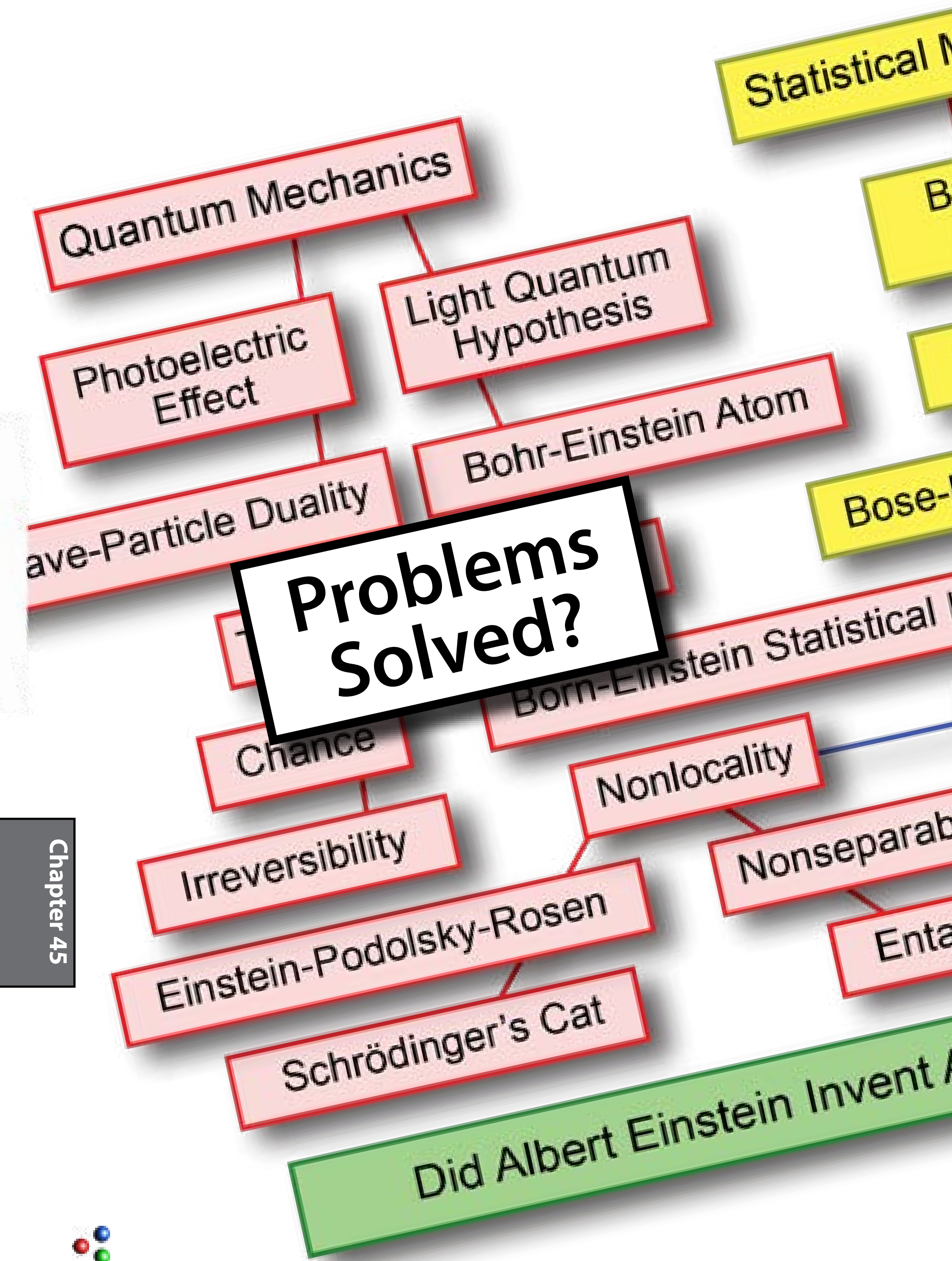
Statistical
Quantum Mechanics
Light Quantum Hypothesis
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Problems Solved?
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Did Albert Einstein Invent

Problems Solved?

In the preface we posed thirteen problems for which a deep analysis of Einstein's thinking, especially his idea of an "objective reality," might lead to plausible solutions.

1. The 19th-century problem of microscopic irreversibility
2. Nonlocality, first seen by Einstein in 1905
3. Wave and particle "duality" (1909)
4. The metaphysical question of ontological chance (1916)
5. Nonlocality and "action-at-a-distance" (1927)
6. The "one mystery" of the two-slit experiment
7. The measurement problem (1930)
8. The role of a "conscious observer" (1930)
9. Entanglement and "spooky" action-at-a-distance (1935)
10. Schrödinger's Cat - dead *and* alive? (1936)
11. No "hidden variables," but hidden constants (1952)
12. Conflict between relativity and quantum mechanics?
13. Is the universe deterministic or indeterministic?

Our proposed solutions are *radical*, if only compared to decades of confusion and mystery surrounding quantum mechanics, but we hope that you find most of them visualizable and intuitive, not characteristics normally associated with the quantum.

Microscopic Irreversibility

Problem: In classical mechanics, microscopic particle collisions are time reversible, conserving entropy and information. Neither entropy, nor more importantly information, can increase in a deterministic, classical world. Ludwig Boltzmann showed that random collisions could increase the macroscopic entropy, but reversing the time would decrease it again.. Thus the puzzle, how to reconcile macroscopic entropy with microscopic reversibility.

Solution: Reversibility fails when any matter interacts with radiation, e.g., emission of a photon during the collision, or changes (quantum jumps) between internal energy levels, are taken into account. Any quantum process with such transitions involves ontological chance as discovered by Einstein in 1916. Interaction with light introduces random changes in the energy and momentum of either or both particles. If all particle motions could be reversed, the absorption of a photon with the same energy in the opposite direction at the correct moment is not impossible, but statistically very unlikely to occur.

Comment: As Einstein noted in 1909, emission processes are not "invertible." There are outgoing spherical waves, but incoming spherical waves are never seen. Josef Loschmidt's reversibility paradox is removed. Ernst Zermelo's recurrence objection is also eliminated because the recurrence of original, low entropy states is prevented by the expansion of the universe. The environment is always different. See chapters 11 and 12.

Nonlocality

Problem: When a light wave, possibly carrying energy, spreads out in all directions, how can that energy be suddenly collected together at one point to eject an electron in the photoelectric effect? In 1909 Einstein feared this instantaneous "collapse" of the light wave was a violation of his special theory of relativity?

Solution: It took Einstein some years to see that the light wave is really just the abstract probability of finding his light quanta or material particles. One can think of the probability of finding a particle somewhere other than where it is actually found as suddenly going to zero, which gives the appearance of a "collapse." In any case no matter, energy, or even abstract information is moving when a particle is found somewhere. Nonlocality is only the *appearance* of change in spatially separated places. Nothing objectively real is moving.

Comment: Probabilities are solutions to the Schrödinger equation, determined by the boundary conditions of the experiment and the wavelength of incoming particles. Probabilities for other particles in the space do not change when one particle is detected. See chapters 6, 9, and 23.

Wave-Particle Duality

Problem: Popular interpretations of quantum mechanics describe quantum objects as sometimes waves and sometimes particles, or perhaps both at the same time?

Solution: Particles are real objects. Einstein was first to see waves as imaginary, mathematical fictions, “ghostly” and “guiding” fields, that allow us to calculate probabilities for finding particles. These waves have a statistical power over the location of particles that is the one deep mystery of quantum mechanics.

Particles are *discrete* discontinuous localized quanta of matter or energy. It was Einstein in 1905 who proved the existence of matter particles and hypothesized light particles, the prototypes of the two families of elementary particles in the “standard model” - fermions and bosons. Twenty years later, he discovered their different quantum statistics!

Waves, or wave functions, are mathematical solutions to the Schrödinger equation, with *continuous* values in all space, which provide probabilities for finding particles in a given place and in a specific quantum state.

Comment: The time evolution of the wave function is not the motion of the particle. It is only the best estimate of where the particle might be found. *Continuous* wave functions evolve deterministically. Particles are *discrete* and change their quantum states indeterministically.

As Max Born described it “The motion of the particle follows the laws of probability, but the probability itself propagates in accord with causal laws.“

Particles are physics. Waves, and fields, are metaphysics.

See chapter 9.

Ontological Chance

Problem: If every collision between material particles is controlled completely by the distribution and motions of all other particles together with the natural force laws of classical physics, then there is only one possible future.

Solution: In modern physics, all interactions between material particles are mediated by the exchange of energy particles. Einstein’s light quanta (photons) are the mediating particles for electromagnetic radiation. In 1916, Einstein showed that these energy particle exchanges always involve chance. Quantum mechanics is statistical, opening the possibilities needed for free will, the "free choice" of the experimenter, and "free creations of the human mind."

Comment: The emergence of classical laws and apparent deterministic causality occurs whenever the number of particles grows large so quantum randomness can be averaged over. Bohr's "correspondence principle" claims classicality also occurs when quantum numbers are large.

The "quantum-to-classical transition" occurs when the mass of an object *m* is very large compared to Planck's constant *h*, so the uncertainty $\Delta v \, \Delta x \geq h / m$ is very small. See chapters 1 and 11.

Nonlocality and Action-at-a-Distance

Problem: Einstein's 1927 presentation at the fifth Solvay conference was his first public description of an issue that had bothered him since 1905. He thought he saw events at two places in a spacelike separation happening simultaneously. His special theory of relativity claims to show the *impossibility of simultaneity*.

Solution: Einstein's blackboard drawing shows us that the electron's wave function propagates in all directions, but when the particle appears, all of it is found at a single point.

Using Einstein's idea of "objective reality," without any interactions that could change the momentum, the particle must have traveled in a straight line from the origin to the point where it is found. The properties of the particle considered by Einstein in 1927 could have evolved *locally* from the start of the experiment as what we called "hidden constants" of the motion.

Comment: There was no "action" by either particle on the other in this case, so we call it "knowledge-at-a-distance." See chapters 9, 17, 18, and 23.

Two-Slit Experiment

Problem: In experiments where a single particle travels to the screen at a time, large numbers of experiments show interference patterns when both slits are open, suggesting that a particle must move through both slits in order to "interfere with itself."

Solution: Solutions to the time-independent Schrödinger equation for the given boundary conditions - two open slits, screen, particle wavelength - are different for the case of one slit open. In Einstein's "objective reality," the particle conserves all its properties and goes through only one slit. Probability amplitudes of the wave function are different when two slits are open, explaining interference.

Comment: Feynman's path integral formulation of quantum mechanics suggests the same solution. His "virtual particles" explore all space (the "sum over paths") as they determine the variational minimum for least action, thus the resulting probability amplitude wave function can be said to "know" which holes are open. How abstract probabilities influence the particles' motions is the one remaining mystery in quantum mechanics.

Bohmian mechanics also defends a particle that goes through one slit reacting to probabilities that are based on two slits being open. See chapter 33.

Measurement Problem

Problem: John von Neumann saw a *logical* problem with two distinct (indeed, opposing) processes, the unitary, *continuous*, and deterministic time evolution of the Schrödinger equation versus the non-unitary, *discontinuous*, and indeterministic "collapse of the wave function." Decoherence theorists and many-worlders are convinced that quantum mechanics should be based on the wave function alone. There are no particles, they say. Schrödinger agreed.

Solution: We can think of the time evolution of a system as involving these two processes, but one after the other. First, the system evolves as a probability amplitude wave function according to the time-dependent Schrödinger equation. Then, at an unknown time (which bothers the critics), the particle appears somewhere.

The time of collapse may simply be the moment an experimenter makes a measurement. Measurement requires the recording of *irreversible* information about the location of the particle, as von

Neumann knew. It does not have to be in the mind of a conscious observer.

Comment: This problem shows why we need to get "beyond logic" in the philosophy of science.

Conscious Observer

Problem: The Copenhagen Interpretation and many of its supporters, e.g., Werner Heisenberg, John von Neumann, Eugene Wigner, considered a measurement not complete until it reaches the mind of the observer. They asked where is the "cut" (*Schnitt*) between the experiment and the mind?

Solution: Information must be recorded *irreversibly* before any observer can know the results of a measurement. Data recorded (ontologically) by a measuring instrument creates new information in the universe. But so does any newly created information structure in nature without an observer. Einstein wanted objective reality to be independent of observers, but there are measurements that are a "free choice" of the experimenter, creating a new part of reality.

Comment: We might say that information becomes known (epistemological) when it is recorded in the world and then seen by a human observer. But most new information created is ontological, the universe is *observing itself*. See chapter 25.

Entanglement and "Spooky" Action-at-a-Distance

Problem: In his 1935 EPR paper, Einstein discussed two particles traveling away from the center. He used conservation principles to show that measuring one particle gives information about the other without measuring it directly. We have shown the two particles' properties could have evolved *locally* from their original values at the center no matter how far the particles are apart, as long as no interaction with the environment has altered their values and destroyed their "coherence." But a true *nonlocality* appears in David Bohm's 1952 version the EPR experiment, in which electron spin components are measured instead of linear momenta.

Solution: As the electrons travel apart, each one stays in its state by conservation laws. Their spins and linear momenta are conserved. The left-moving particle electron is say $-p$. The other is p. The total linear momentum is zero. Similarly their total spin is zero. If one electron is spin *ħ/2*, the other is exactly opposite. But the original process of entanglement has not left the electron spins with a definite spatial direction.

When Alice uses her "free choice" of which angle to measure the spin (or polarization) component, she adds new information which was not present at the original entanglement. Alice's measurement decoheres and disentangles the two-particle wave function. The particles now appear in a spacelike separation equidistant from the origin. The *directionless* and opposite spins are projected by her measurement into spin components, say z+ and z-. If Bob then measures at the same angle, he gets the perfectly correlated opposite value.

Comments: It is part of the deep mystery of quantum mechanics how the spatial directions of the two spins, created by a measurement of the two-particle wave function anywhere, come out in perfectly correlated directions. But had they not, something even worse would have happened. Symmetry and conservation laws would have been violated.

Schrödinger's Cat

Problem: Erwin Schrödinger imagined that the time evolution of his equation could start with a microscopic radioactive nucleus in a superposition of decayed and undecayed state, leading to a macroscopic cat in a similar superposition. When he suggested it, he was criticizing, really ridiculing, what he thought was an absurd consequence of Paul Dirac's *principle of superposition*, with its probabilities for a system to be in different states

Solution: Schrödinger was just criticizing superposition and its probabilities. There is never an *individual* cat simultaneously dead and alive. What the superposition of possible states in quantum mechanics gives us are only *probabilities* for the cat being dead *or* alive. The predicted *probabilities* are empirically confirmed by the *statistics* in large numbers of identical experiments, each one of which ends up with either a live or dead cat.

Comment: The individual radioactive nucleus is never in a superposition of decayed and not decayed. Quantum mechanics gives us the *probabilities* of a decay or remaining undecayed. Once there is a decay, the evolution results in a dead cat. If no decay, then a live cat. Indeed, not only do macroscopic superpositions of cats not exist, the radioactive nucleus is not in a superposition. There are no macroscopic superpositions because there are no microscopic superpositions either.

No "Hidden Variables," but Hidden Constants

Problem: David Bohm suggested that "hidden variables" could instantaneously communicate information between entangled particles to perfectly correlate their properties at great distances, specifically the opposite +1/2 and -1/2 electron spins of a two-electron system with total spin zero.

Solution: In our adaptation of Einstein's "objective reality," the particles are generated with individual properties, momenta, angular momenta, spins, and they conserve these properties until they are measured. These properties are carried along "locally" with the particles, so do not violate special relativity as Einstein feared.

While there might not be Bohmian "hidden variables," we can call these conserved quantities "hidden constants" ("constants of the motion," hidden in plain sight). They explain the *appearance* of Einstein's "spooky" action-at-a-distance. Our hidden constants can explain the original EPR results, but they cannot explain the measurements of electron spin components, which are *created* by Alice's measurement.

Comment: The two spin components, say z+ and z-, are Alice's *nonlocal* projections of the opposing spins that traveled *locally* from the origin. The *nonlocal* aspect is that these spin components have perfectly opposing directions even though they are about to be greatly separated, once the two-particle wave function has collapsed into the product of two single-particle wave functions.

Of course if the opposing spins of the electrons that travel *locally* from the origin did not remain perfectly anti-correlated when measured and projected into a specific direction, that would be a violation of the conservation laws.

Is the Universe Deterministic or Indeterministic?

Problem: Einstein was well known, especially in his younger years, for hoping quantum physics could be found to be a deterministic theory. When in 1916 he discovered the randomness in quantum physics, he called chance a "weakness in the theory." And many times he insisted that "God does not play dice." Many of the alternative "interpretations" of quantum mechanics are deterministic. See chapters 30, 31, 32, and 34.

Solution: Einstein had fully accepted the indeterministic nature of quantum mechanics by some time around 1930. But his colleagues paid little attention to his concerns, which had turned entirely to the *nonlocal* aspects of quantum mechanics.

Comment: Without indeterminism, we could not have a creative universe and Einstein's "free creations of the human mind."

What Is Quantized?

The "quantum condition" describes the underlying deep reason for the existence of discrete objects.

For Bohr in 1913, it was the angular momentum of electrons in their orbits, as suggested by J.W.Nicholson. For Louis de Broglie in 1924 it was that the linear momentum $p = h/\lambda$ and that an integer number of wavelengths fits around an electron orbit. For Heisenberg in 1925, it was the non-commutation of momentum and position operator matrices, and in 1927 his resulting uncertainty principle $\Delta p \Delta x = h$. In Bohr's otherwise obscure Como lecture of 1927, he showed that $\Delta v \Delta t = 1$, thus deriving the uncertainty principle with no reference to measurements as "disturbances," and embarrassing Heisenberg.

Multiplying $\Delta v \Delta t = 1$ by Max Planck's constant h, and noting $E = hv$, we have $\Delta E \Delta t = \Delta p \Delta x = \Delta J \Delta \varphi = h$. All of these expressions have the same physical dimensions as angular momentum J.

As Erwin Schrödinger explained, it is always *action, or angular momentum, that is being quantized*. Momentum *p*, position *x*, energy *E*, and time *t*, all take on continuous values. It is the angular momentum or spin *J* that comes in integer multiples of *h*.

Any interaction of radiation and matter involves at least one unit of Planck's quantum of action *h*, which first appeared in 1900, though only as a heuristic mathematical device, not the radical core idea of a new physics. That was seen first by Einstein, like so many of the quantum mechanical concepts he saw long before the "founders" developed their powerful quantum calculation methods.

The Bottom Line

There is no microscopic reversibility.

There is no nonlocality in the form of one event *acting* on another in a spacelike separation. There are simultaneous synchronized events in a spacelike separation, which Einstein feared violated his special theory of relativity. They do not.

Particles are real physics. Waves are imaginary. Fields are metaphysics.

Ontological chance exists. Without it, nothing ever happens.

Nothing physically "collapses" when a possibility is actualized.

The "one mystery" of quantum mechanics is how probability waves control the statistical motions of particles to produce interference effects.

The measurement problem is explained as when new information is irreducibly recorded in the measurement apparatus. Local entropy is reduced. Global entropy increases.

There is no nonseparability. Particles separate as soon one leaves the other's light cone. But two entangled particles retain their perfect correlation of properties as required by the conservation laws, until one interacts with something in the environment and decoheres. A measurement begins with the properties of the particles still correlated. It ends with decorrelation and disentanglement. The mysterious power of the two-particle wave function separates into single-particle functions with their new spatial spin direction also perfectly correlated. But the particular spin component direction chosen by Alice was not known at the origin. It can be viewed as new information appearing nonlocally, i.e. simultaneously in a spacelike separation.

"Spooky action-at-a-distance" is just the *appearance* of communication or interaction when entangled particles are measured at separation and found to remain perfectly correlated. There is no "action" by one particle on the other. It is simply "knowledge-at-a-distance."

There is no conflict between special relativity and quantum mechanics, though there would have been if the probability waves had been carrying energy or matter.

Schrödinger's cat will always be found as alive, dead, or dying if the nuclear decay has occurred. This is just as individual objects are never in a superposition, never in two places at the same time.

There is one world. It is a quantum world. The world *appears* classical for objects with large mass. And it is indeterministic, which opens *alternative possibilities* for an open, free, and creative future, for Einstein's "free creations of the human mind."

Einstein's "objective reality" can explain the world with standard quantum mechanics, so much of which he discovered or created.

His many criticisms and objections did not prevent him from seeing the truly mysterious aspects of quantum physics well before his colleagues, who often get the credit that belongs to him.

How to Restore Credit to Einstein

To correct this problem, historians of physics and especially teachers of quantum mechanics must change the way they discuss and especially to *teach* Einstein's contributions to physics.

His paper explaining Brownian motion should be taught as the first proof that matter is not continuous, but discrete. It consists of quanta. He thought he had proved Boltzmann's controversial hypothesis of atoms.

His paper explaining the "photoelectric effect," for which he was awarded the Nobel Prize, should be taught as the revolutionary hypothesis that light energy also comes in discrete quanta *hν*.

In these two 1905 papers, Einstein was the first to see the elements in today's "standard model" of particle physics - the fermions (matter) and the bosons (energy). For this work alone, Einstein should be seen as the true founder of quantum mechanics

His third paper in 1905, explaining relativity, should not overshadow his quantization of matter and energy and his fourth paper that year, showing their interchangeability - $E = mc^2$.

His 1907 paper explaining the anomalous specific heat of certain atoms should be taught as the discovery of energy levels in atoms and the "jumps" between them, six years before Niels Bohr's quantum jumps between his postulated energy levels in the atom.

Einstein's 1909 paper explaining wave-particle duality should be taught as the continuous wave (and later the wave function ψ) giving us the *probability* of finding a discrete particle. Quantum mechanics is *statistical*!

His 1916 paper on transition probabilities between energy levels, which discovered the stimulated emission of radiation behind today's lasers, should be taught as the discovery of ontological *chance* in nature whenever matter and radiation interact. The interactions always involve at least one quantum of action *h*. They introduce statistics and indeterminacy a decade before Werner Heisenberg's uncertainty principle.

Arthur Holly Compton's 1923 explanation of the "Compton effect," which confirmed Einstein's 1916 prediction that particles of light have momentum as well as energy, should be taught as Einstein's deep confidence in conservation principles, so that the motions and paths of quantum particles *objectively* exist and at all times are obeying those conservation laws for momentum and energy. Einstein had used these fundamental principles to invalidate Niels Bohr's final attempt to deny Einstein's light quantum hypothesis in 1924, in the Bohr-Kramers-Slater paper. This work should be taught as the basis for Einstein's belief in an "objective reality."

Particles don't cease to exist, or appear simultaneously at multiple places, as claimed by the Copenhagen Interpretation of quantum mechanics. Just because we can't continuously measure paths does not mean that particles do not exist until we observe them.

Einstein's 1925 papers based on Satyendra Nath Bose's very simple quantum derivation of the Planck law in 1924, should be taught as

Einstein's discovery of the *indistinguishability* of elementary particles and their consequent strange and different statistics for half-spin "fermions"and unit-spin "bosons."

Einstein's misunderstood and ignored presentation at the Solvay conference of 1927 showing the *nonlocal* behavior in a single particle passing through a slit should be taught as the beginning of his 1935 EPR paper, when he showed that two particles a great distance apart can acquire perfectly correlated properties instantaneously, his discovery of nonseparability and entanglement.

Poincaré and Einstein

Some historians of science have pointed out how much Einstein was inspired by Henri Poincaré's great book *Science and Hypothesis.*

Many of Einstein's biographers have described the young Einstein's colleagues who met frequently to discuss new ideas in philosophy and physics. They called themselves the Olympia Academy. After a frugal evening meal of sausage, cheese, fruits, honey, and tea, they read and discussed the great works of David Hume, John Stuart Mill, Ernst Mach, and Karl Pearson. Several weeks were spent on Henri Poincare's *La Science et l'Hypothèse*.

Recently a few scholars have shown that in his "miracle year" of 1905 Einstein solved three great problems described by Poincaré, just one year after his book had been translated into German. Arthur I. Miller cited three problems he thought Poincaré felt were "pressing;" the failed attempts to detect the motion of Earth through the "ether," the photoelectric effect, and Brownian motion. [1] A close reading of Poincaré's book shows that great thinker suggested several more problems to Einstein, most importantly the principle of relativity, but also the one-way increase of entropy with its problem of irreversibility, Maxwell's demon, the question of determinism or indeterminism, and amazingly "action-at-a-distance." We now realize that in quantum mechanics what Einstein discovered is only "knowledge-at-a-distance."

We hope to have shown that the far-seeing Einstein grappled with all these problems, a few unsuccessfully but always creatively, between reading Poincaré in 1904 and his death five decades later.

1 Miller, 2002, p.185. Rigden 2005, p.8, Holt, 2018, p.5