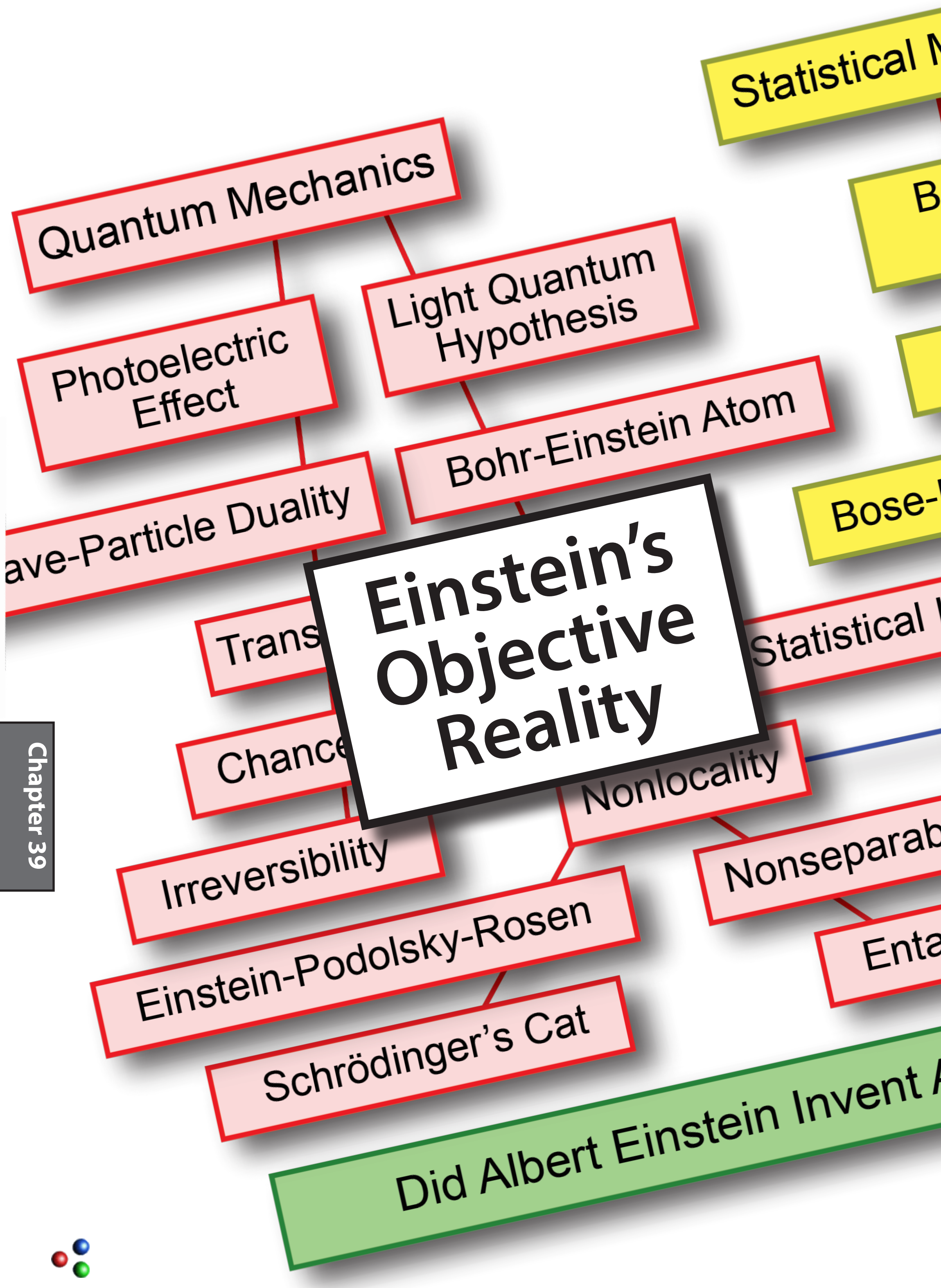
Statistical
Quantum Mechanics
Light Quantum Hypothesis
Photoelectric Effect
Bohr-Einstein Atom
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ave-Particle Duality
Einstein's Objective Reality
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Statistical
Chance
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Einstein-Podolsky-Rosen
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Schrödinger's Cat
Did Albert Einstein Invent

Einstein's Objective Reality

In his search for an "objective reality," Einstein asked whether a particle has a determinate position just before it is measured. The Copenhagen view is that a particle's position, path, and other properties only come into existence when they are measured.

Let's assume that material particles have definite paths as they travel from collision to collision, as Ludwig Boltzmann's statistical mechanics assumed. They are not brought into existence by the actions of a physicist, as Werner Heisenberg claimed, although some values, like spin components, may be created by the "free choice" of the experimenter as to what to measure.

In an objective reality, particle paths and their instantaneous positions are always *determinate* in principle, though not *determinable* in practice without experimental measurements, which might alter the particle's properties irreversibly.

Let's identify Einstein's "objective reality" with his "local reality," in which all "actions" or "interactions" are "local." These include classical "actions-at-a-distance" in Newtonian mechanics and Maxwell electromagnetism that are mediated by electromagnetic or gravitational fields, understood as the interchange of particles at speeds less than or equal to the speed of light.

As we saw in chapter 23, "nonlocality" usually means what Einstein discovered as early as 1905 and much later called "spooky action-at-a-distance," because it *appears* to require a particle or its associated wave at one point in space to act on another point far away in a spacelike separation.

"Nonlocality" defined this way as *actions* by one particle on another at a distance simply does not exist.

But "entangled" particles in a spacelike separation *appearing* to be changing their properties "simultaneously" in at least one frame of reference certainly does exist. A measurement by Alice or Bob to determine the electron spin components in a specific spatial direction is a measurement of the second kind.

This is nonlocality in the original sense of Einstein in 1905 and 1927. It appears to violate his "impossibility of simultaneity."

Entanglement and Objective Reality

In our application of Einstein's "objective reality" to such entanglement (chapters 26 to 29), we have shown that such purportedly "nonlocal actions" do not involve any interchanges, nothing material or energetic is moving, no information can be sent between the particles, etc.

The *appearance* of instantaneous interactions between objects in a spacelike separation arises because "orthodox" quantum physics claims that objects do not have properties until they are measured. It assumes that perfectly correlated properties in two separated particles are newly created when they are measured, instead of being already present in the particles as they "objectively" and "locally" travel from their initial entanglement.

In chapter 29 we showed that most properties of each particle have traveled with them from the moment of their entanglement.

To be sure, some new property values may be created in a measurement, because the observer has a "free choice" as to what to measure. The paradigm example is a measurement of electron spin or photon polarization in a definite spatial direction.

We can still use Einstein's demands for conservation of spin and symmetry to explain why the two measurements by Alice and Bob always conserve the total spin as zero. But it is not obvious how two events in a spacelike separation that appear simultaneously (in the special frame in which the measurement apparatus is at rest) can correlate arbitrary spin component *directions* perfectly.

They violate Einstein's "impossibility of simultaneity."

Our best explanation is to credit perfect correlation to the deeply mysterious power of the wave function ψ to "influence" events at great spacelike separations.

This was Schrödinger's immediate reaction to Einstein's EPR paper in 1935. The coherent two-particle wave function is not separable into the product of two single-particle wave functions, but when it does decohere, the property of the chosen spin directions is conserved for each electron.

The Two-Slit Experiment and Objective Reality

Einstein's "objective reality" visualizes particles as having continuous paths. In particlular, the path of a particle in the two-slit experiment always goes through just one of the slits.[1]

The quantum wave function, by comparison, goes through both slits when they are open, producing an interference pattern quite different from those with only one of the slits open.

This view explains the two-slit experiment completely, without worrying, as Richard Feynman did on his "logical tightrope," how a particle might go through both splits, for example, by being in two places at the same time. (See chapter 33.)

But Feynman is nevertheless right that the two-slit experiment contains "one" deep mystery in quantum mechanics.

How does the quantum wave function "influence" the motion of particles so that they reproduce (statistically) the interference patterns seen in the two-slit experiment?

The squared modulus of the wave function $|\psi|^2$ is a probability field. Gravitational and electromagnetic fields allow us to calculate the forces on a test particle, then solve for the particle motion. But a probability field exerts no known force. And if it were a force, it would need to act statistically, where gravitational and electromagnetic forces are deterministic.

Irreversibility and Objective Reality

Einstein's "objective reality" allows us to visualize colliding particles as having determinate but not determinable paths. Ludwig Boltzmann and his colleagues saw that those paths might conserve the path information. That would, if we could reverse the paths, lead to a decrease in entropy in violation of the second law of thermodynamics.

To this "local reality" of paths conserving information we can add Einstein's 1917 discovery of ontological chance when light interacts with matter, absorbing or emitting radiation. Photon emission and absorption during molecular collisions deflect the molecules randomly from their paths.

1 Bohmian mechanics agrees with this. See chapter 30.

This destroys the path information and molecular correlations, justifying Boltzmann's assumption of "molecular chaos" (*molekular ungeordnete*) as well as Maxwell's earlier assumption that molecular velocities may not actually be correlated as determinism suggests.

Of the dozen or so mysteries and paradoxes in quantum mechanics described in our preface, Einstein's "objective reality" analysis contributes to solutions for some of the most important - nonlocality, nonseparability, entanglement, the two-slit experiment, and microscopic irreversibility. It also sheds light on others, but we need now to see how Einstein's excellent understanding of quantum physics can resolve a few more..

The wave functions of quantum mechanics produce only *predictions* of the probability of finding the particles themselves at different positions in space, as Einstein himself was first to see. Those probabilities depend on the boundary conditions, like a box confining the standing waves of a harmonic oscillator, the slits in the two-slit experiment, or the nodes in atomic and molecular orbitals confined by the nuclear attraction.

But there is nothing substantial at those points unless a discrete particle is there. And Einstein suspected that reality might consist only of discrete particles. Even space and time might be nothing (i.e., not things). In his 1949 autobiography, he wrote

> Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of "physical reality." In pre-quantum physics there was no doubt as to how this was to be understood. In Newton's theory reality was determined by a material point in space and time; in Maxwell's theory, by the field in space and time. In quantum mechanics it is not so easily seen. [2]

Einstein knows that waves, now wave functions, exert an "influence" over material particles. To Einstein the influence looked like simultaneous events in a spacelike separation, which his theory of relativity thought impossible.

2 Schilpp, 1949, p.81

Whether it is the wave function in the two-slit experiment influencing the locations on the screen, or the collapse of the two-particle wave function into two single-particle wave functions, each with the perfectly correlated spin components needed to conserve total spin, Einstein's "objective reality" lets us see "hidden constants" that act to conserve all those properties and maintain existing symmetries.

> If one asks: does a ψ-function of the quantum theory represent a real factual situation in the same sense in which this is the case of a material system of points or of an electromagnetic field, one hesitates to reply with a simple "yes" or "no"...Does the individual system not have this q-value before the measurement, but only after a measurement when it randomly jumps into this position from somewhere else? But what about the single measured value of q? Did the respective individual system have this q-value even before the measurement? To this question there is no definite answer within the framework of the [quantum] theory, since the measurement is a process which implies a finite disturbance of the system from the outside; it would therefore be thinkable that the system obtains a definite numerical value for q (or p), i.e., the measured numerical value, only through the measurement itself. [3]

But as Werner Heisenberg thought, there are definitely times when an experimenter creates specific values, using her "free choice" of which property to measure. When Alice chooses the angle for her measurement, she disentangles the two-particle wave function. We now have simultaneous events in a spacelike separation. Einstein's symmetry and conservation principles are at work to ensure that Bob's measurement at the same angle conserves the total spin.

Einstein's insight into his EPR paradox never involved this subtle complexity of spinning electrons, although he was the discoverer of quantum statistics that Paul Dirac used to explain electron spins, but his objectively real picture can explain much of what is going on.

The puzzle of the wave function's influence over matter is the remaining "deep metaphysical mystery" of quantum mechanics.

3 Schilpp, 1949, p.81