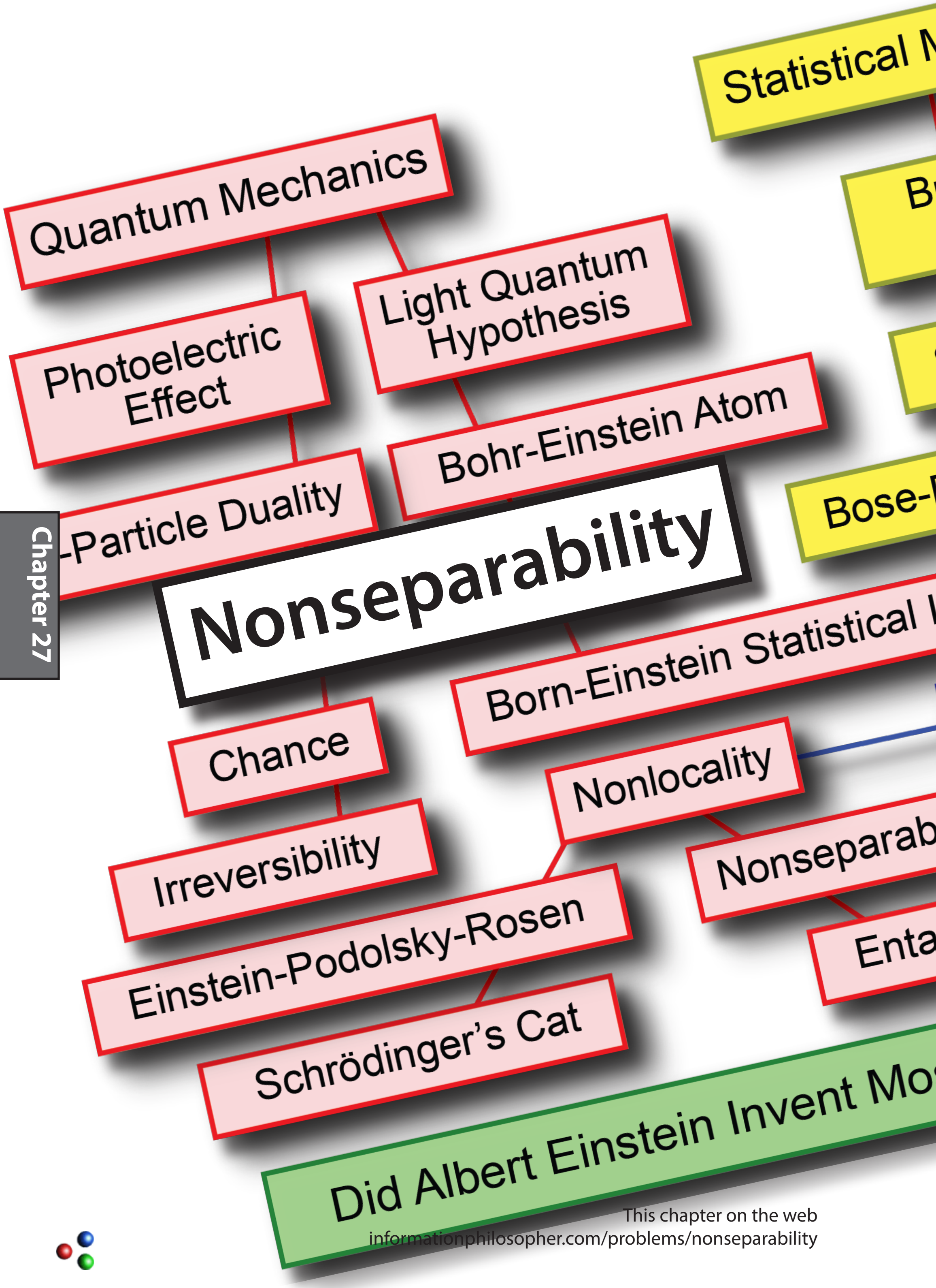

This chapter on the web
informationphilosopher.com/problems/nonseparability

Nonseparability

Entangled particles are described by a single two-particle wave function ψ_{12} that cannot be separated into a product of single-particle wave functions ψ_1 and ψ_2 without a measurement or external interaction that “decoheres” or “disentangles” them.

The question for Albert Einstein and Erwin Schrödinger was how long the particles could retain their correlation as they traveled a great distance apart. Once disentangled, or “decohered,” the two-particle wave function Ψ_{12} can be described as the product of two single-particle wave functions Ψ_1 and Ψ_2 and there will no longer be any quantum interference between them. But entangled particles, it turns out, do not decohere spontaneously. They cannot decohere without an external interaction (like a measurement).

Einstein had objected to *nonlocal* phenomena as early as the Solvay Conference of 1927, when he criticized the collapse of the single-particle wave function as involving instantaneous “action-at-a-distance” that looks like the spherical outgoing wave acting at more than one place on the screen. He had seen single-particle nonlocality as early as his light-quantum hypothesis paper of 1905, as we saw in chapter 23. But we showed that the collapse of the mathematical probabilities $|\Psi|^2$ only involved the disappearance of those probabilities. Without matter or energy moving, there is no “action” being exerted on the particle by the wave.

We can now try to understand the nonseparability of two entangled particles in terms of single-particle nonlocality. The entangled particles share one volume of nonlocality, i.e., wherever the two-particle wave function has non-zero values of $|\Psi_{12}|^2$.

Quantum mechanics says that *either* particle has the same possibility (with calculable probability) of appearing at any particular location in this volume. Just as with the single-particle nonlocality, in standard quantum mechanics we cannot say where the two particles “are.” Either one may be anywhere up to the moment of “collapse” of the two-particle wave function. But conservation principles require that whenever they finally do appear, it will be equidistant from the origin, in order to conserve linear momentum.

And more importantly, conservation principles and symmetry require that measurements of any particular property of the two particles find that they too are perfectly correlated, as we shall see in chapter 29.

Einstein's "objective reality" assumes that the particles simply have continuous paths from the start of the experiment to the final measurement(s), although the limits of quantum measurement may never allow us to "know" those paths.

It is the fundamental principle of conservation that governs the correlated outcome, not some hypothetical, faster than light, communication of information between the particles.

But just because we cannot say or know a particle's continuous path does not prove that it does not have a continuous path

EPR According to Quantum Theory

Quantum mechanics describes the probability amplitude wave function ψ_{12} of any two-particle system as in a *superposition* of two-particle states. It is not separable into a product of single-particle states, and there is no information about individual particles traveling along observable paths.

The Copenhagen Interpretation, by contrast, claims that quantum systems do not have properties until they are observed. And not merely measured by apparatus that records data. The result of the measurement must reach the *mind* of the experimenter, according to JOHN VON NEUMANN's "psycho-physical parallelism."

Einstein, however, frequently asked whether the particle has a position at the moment before it is measured? "Is the moon only there when we look at it," he quipped. And 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."

Einstein took the Copenhageners as saying the two particles may actually be anywhere that Ψ_{12} is non-zero, then they jump to places that conserve the momentum only at the measurement.

The particles are thought to be in a superposition of all possible momentum or position eigenstates, as we see in the next chapter.

Now when entangled particles experience a random interaction with something in the environment (described as “decoherence”), or an experimental measurement by an observer, the two-particle wave function “collapses.”

In the standard quantum physics view, all the possibilities/probabilities that are not actualized go to zero, just as with the single particle wave function. But now, two particles appear, *simultaneously* in a special frame in which their center of mass is not moving. In other moving frames, either particle may *appear to appear* before the other.

The two particles appear simultaneously, in a spacelike separation, now disentangled, and symmetrically located about the point of the interaction which entangled them.

If they did not appear as symmetrically as they had been at the beginning, both conservation laws and underlying principles of symmetry would be violated.

In Einstein’s “objective reality” picture, no faster-than-light signaling is involved. There is no “action” going from one particle to the other. Their linear momenta, correlated at their moment of entanglement, always are correlated “locally” as they travel along at the particles’ speed.

The fact that momenta, and most of their properties, are found synchronized, perfectly correlated, at later times, is because they are always correlated until a disturbance occurs, e.g., an interaction with the environment or a measurement by an observer.

It is only once a disentangling interaction occurs with either particle, that further interactions do nothing to the other, as Einstein requires for his *separability principle* (*Trennungsprinzip*).

> But on one supposition we should, in my opinion, absolutely hold fast: the real factual situation of the system S_2 is independent of what is done with the system S_1, which is spatially separated from the former.[1]

S_1 only *appears* to “act-at-a-distance” on S_2 if we assume that S_2 lacks properties until it is measured.

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[1] Einstein, 1949a, p.85