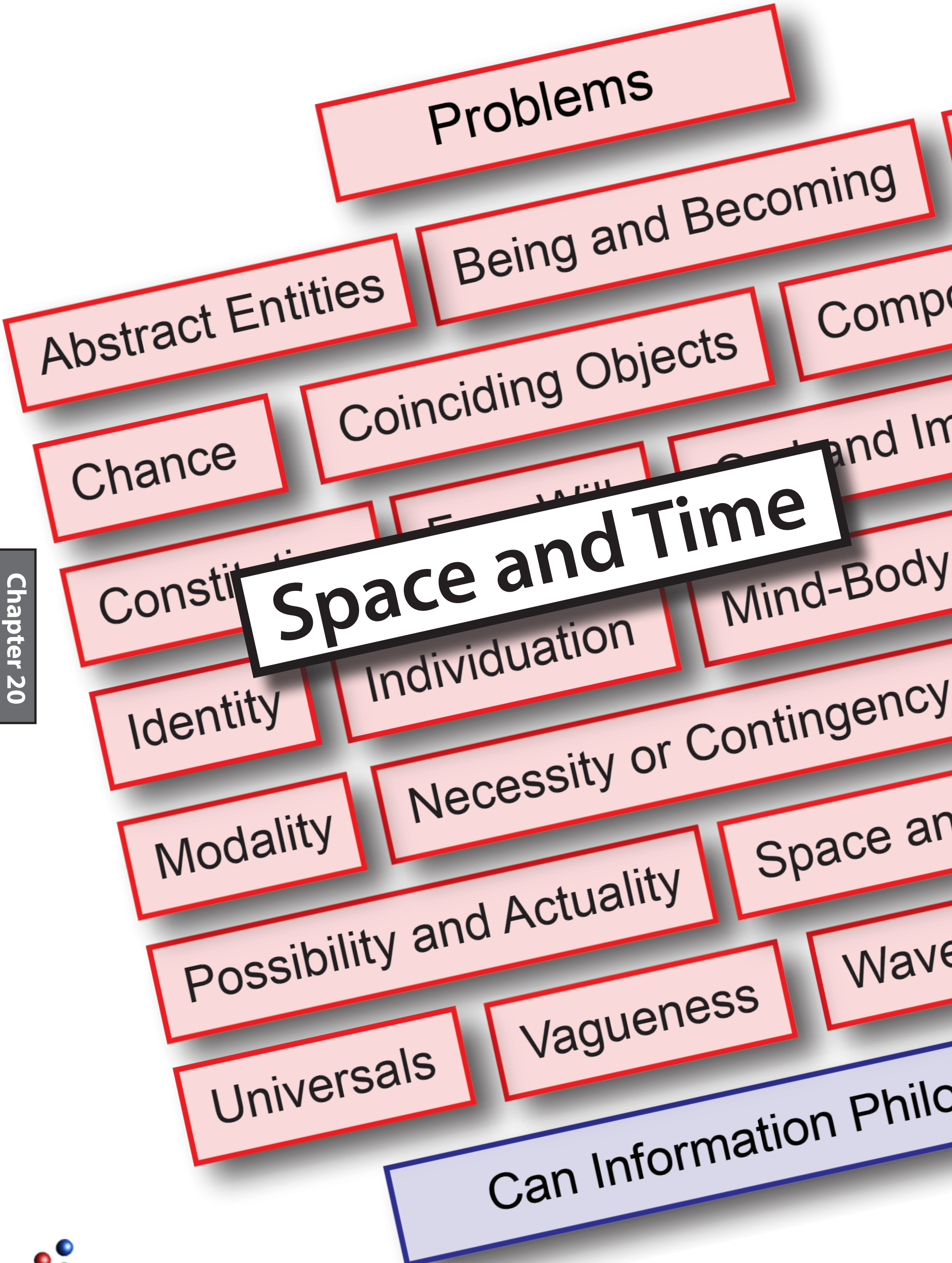
Problems
Being and Becoming
Abstract Entities
Coinciding Objects
Chance
Space and Time
Mind-Body
Individuation
Identity
Modality
Necessity or Contingency
Possibility and Actuality
Universals
Vagueness

# Space and Time

Modern investigations into the fundamental nature of space and time have produced a number of paradoxes and puzzles that also might benefit from a careful examination of the information content in the problem. An information metaphysicist might throw new light on nonlocality, entanglement, spooky action-at-a-distance, the uncertainty principle, and even eliminate the conflict between special relativity and quantum mechanics!

Space and time form an immaterial coordinate system that allows us to keep track of material events, the positions and velocities of the fundamental particles that make up every body in the universe. As such, space and time are pure information, a set of numbers that we use to describe matter in motion.

When Immanuel Kant described space and time as *a priori* forms of perception, he was right that scientists and philosophers impose the four-dimensional coordinate system on the material world. But he was wrong that the coordinate geometry must therefore be a flat Euclidean space. That is an empirical and contingent fact, to be discovered *a posteriori*.

Albert Einstein's theories of relativity have wrenched the metaphysics of space and time away from Kant's common-sense intuitive extrapolation from everyday experience.

Einstein's special relativity has shown that coordinate values in space and time depend on (are relative to) the velocity of the reference frame being used. It raises doubts about whether there is any "preferred" or "absolute" frame of reference in the universe.

And Einstein's theory of general relativity added new properties to space that depend on the overall distribution of matter. He showed that the motion of a material test particle follows a geodesic (the shortest distance between two points) through a curved space, where the curvature is produced by all the other matter in the universe.

At a deep, metaphysical level the standard view of gravitational forces acting between all material particles has been replaced by geometry. The abstract immaterial curvature of space-time has the power to influence the motion of a test particle.

It is one thing to say that something as *immaterial* as space itself is just information about the world. It is another to give that immaterial information a kind of power over the material world, a power that depends entirely on the geometry of the environment.

## Space and Time in Quantum Physics

For over thirty years, from his 1905 discovery of *nonlocal* phenomena in his *light-quantum hypothesis* as an explanation of the photoelectric effect, until 1935, when he showed that two particles could exhibit nonlocal effects between themselves that Erwin Schrödinger called *entanglement*, Einstein was concerned about abstract functions of spatial coordinates that seemed to have a strange power to control the motion of material particles, a power that seemed to him to travel faster than the speed of light, violating his principle of relativity that nothing travels faster than light.



Einstein's first insight into these abstract functions may have started in 1905, but he made it quite clear at the Salzburg Congress in 1909. How exactly does the classical intensity of a light wave control the number of light particles at each point, he wondered.

The classical wave theory assumes that light from a point source travels off as a spherical wave in all directions. But in the photoelectric effect, Einstein showed that all of the energy in a light quantum is available at a single point to eject an electron.

> "The usual conception, that the energy of light is continuously distributed over the space through which it propagates, encounters very serious difficulties when one attempts to explain the photoelectric phenomena... one can conceive of the ejection of electrons by light in the following way. Energy quanta penetrate into the surface layer of the body, and their energy is transformed, at least in part, into kinetic energy of electrons. The simplest way to imagine this is that a light quantum delivers its entire energy to a single electron." [1]

Does the energy spread out as a light wave in space, then somehow collect itself at one point, moving faster than light to do so?

1 Einstein (1905) 'A Heuristic Viewpoint on the Production and Transformation of Light,' English translation - *American Journal of Physics*, 33, 5, 367

Einstein already in 1905 saw something *nonlocal* about the photon and saw that there is both a wave aspect and a particle aspect to electromagnetic radiation. In 1909 he emphasized the dualist aspect and described the wave-particle relationship more clearly than it is usually presented today, with all the current confusion about whether photons and electrons are waves or particles or both.

Einstein greatly expanded the 1905 light-quantum hypothesis in his presentation at the Salzburg conference in September, 1909. He argued that the interaction of radiation and matter involves elementary processes that are not reversible, providing a deep insight into the *irreversibility* of natural processes. The irreversibility of matter-radiation interactions can put microscopic statistical mechanics on a firm quantum-mechanical basis.

While *incoming* spherical waves of radiation are mathematically possible, they are not practically achievable and never seen in nature. If outgoing waves are the only ones possible, nature appears to be asymmetric in time. Einstein speculated that the continuous electromagnetic field might be made up of large numbers of discontinuous discrete light quanta - singular points in a field that superimpose collectively to create the wavelike behavior. The parts of a light wave with the greatest intensity would have the largest number of light particles.

Einstein's connection between the wave and the particle is that the wave indicates the probability of finding particles somewhere. The wave is not in any way a particle. It is an abstract field carrying information about the probability of photons in that part of space. Einstein called it a "ghost field" or "guiding field," with a most amazing power over the particles.

The probability amplitude of the wave function includes interference points where the probability of finding a particle is zero! Different null points appear when the second slit in a two-slit experiment is opened. With one slit open, particles are arriving at a given point. Opening a second slit should add more particles to that point in space. Instead it prevents any particles at all from arriving there.

Light falling at a point plus more light gives us no light!

Such is the power of a "ghost field" wave function, carrying only information about probabilities. Abstract information can influence the motions of matter and energy!

We can ask where this information comes from? Similar to the general relativity theory, we find that it is information determined by the distribution of matter nearby, namely the wall with the two slits in it and the location of the particle detection screen.

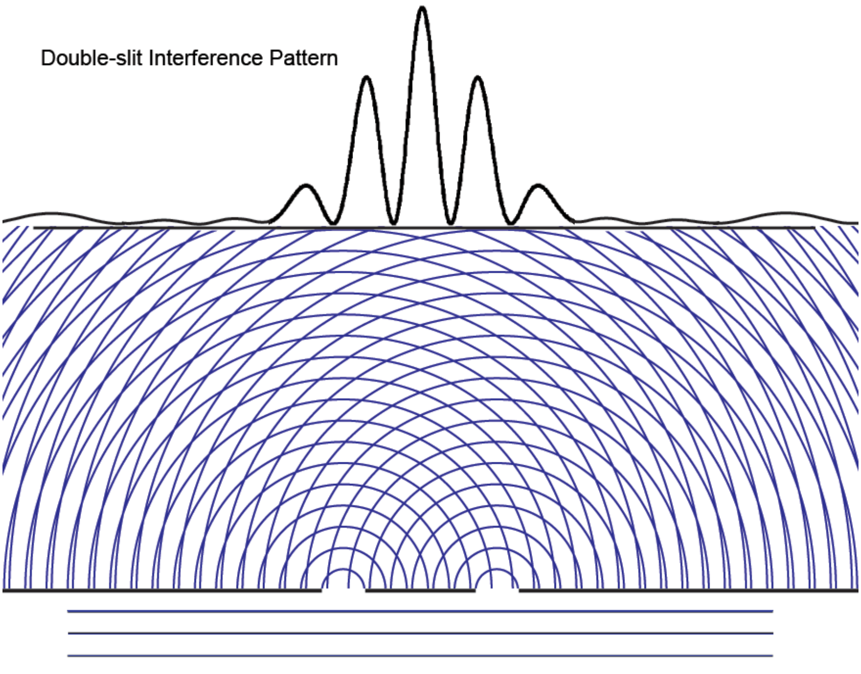


**Figure 25-1.** The points of constructive and destructive interference depend only on the particle wavelength and the location of the screen and the two slits.

These are the "boundary conditions" which, together with the known wavelength of the incoming monochromatic radiation, tells us the probability of finding particles everywhere, including the null points. Think of the waves above as standing waves.

Einstein might have seen that like his general relativity, the possible paths of a quantum particle are also determined by the spatial geometry. The boundary conditions and the wavelength tell us everything about where particles will be found and not found.

The locations of null points where particles are never found, are all static, given the geometry. They are not moving. The fact that water waves are moving, and his sense that the apparent waves might be matter or energy moving, led Einstein to suspect something is moving faster than light, violating his relativity principle.

But if we see the waves as pure information, mere probabilities, we may resolve a problem that remains today as the greatest problem facing interpretations of quantum mechanics, the idea that special relativity and quantum mechanics cannot be reconciled. Let us see how an information metaphysics might resolve it.

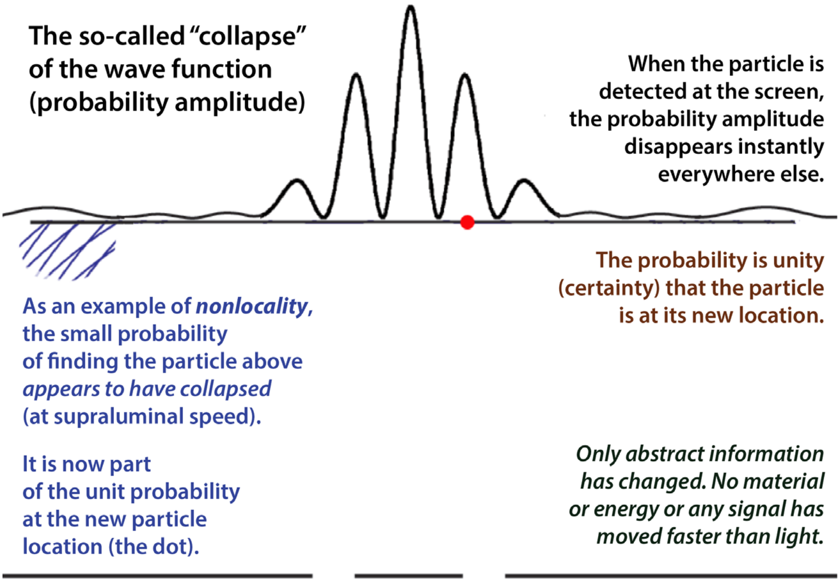


**Figure 25-2.** The appearance of a "collapse" is because the non-zero values of probability amplitude disappear instantly except where a particle is located.



First we must understand why Einstein thought that something might be moving faster than the speed of light. Then we must show that values of the probability amplitude wave function are static in space. Nothing other than the particles is moving at any speed, let alone faster than light.

Although he had been concerned about this for over two decades, it was at the fifth Solvay conference in 1927 that Einstein went to a blackboard and drew the essential problem shown in the above figure. He clearly says that the square of the wave function $|\psi|^2$ gives us the probability of finding a particle somewhere on the screen.

But Einstein oddly fears some kind of action-at-a-distance is preventing that probability from producing an action elsewhere. He says that "implies to my mind a contradiction with the postulate of relativity."[2] As Werner Heisenberg described Einstein's 1927 concern, the experimental detection of the particle at one point exerts a kind of action (reduction of the wave packet) at a distant point.[3] How does the tiny remnant of probability on the left side of the screen "collapse" to the position where the particle is found?

The simple answer is that nothing really "collapses," in the sense of an object like a balloon collapsing, because the probability waves and their null points do not move. There is just an instantaneous change in the probabilities, which happens whenever one possibility among many becomes actualized. That possibility becomes probability one. Other possibilities disappear instantly. Their probabilities become zero, but not because any probabilities move anywhere.

So "collapse" of the wave function is that non-zero probabilities go to zero everywhere, except the point where the particle is found. *Immaterial* information has *changed* everywhere, but not "*moved*."

If nothing but information changes, if no matter or energy moves, then there is no violation of the principle of relativity, and no conflict between relativity and quantum mechanics!



## Nonlocality and Entanglement

Since 1905 Einstein had puzzled over information at one place instantly providing information about a distant place. He dramatized this as "spooky action-at-a-distance" in the 1935 Einstein-Podolsky-Rosen thought experiment with two "entangled" particles.

Einstein's simplest such concern was the case of two electrons that are fired apart from a central point with equal velocities, starting at rest so the total momentum is zero. If we measure electron 1 at a certain point, then we immediately have the information that electron 2 is an equal distance away on the other side of the center.

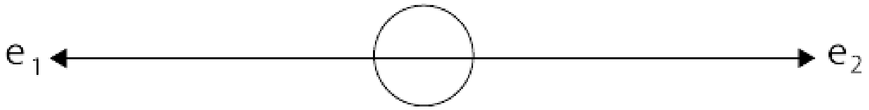


**Figure 25-3.** Particles separate symmetrically from the center.

2 Einstein (1927) *Quantum Theory at the Crossroads: Reconsidering the 1927 Solvay Conference*, G. Bacciagaluppi and A. Valentini, 2009. p.442

3 Heisenberg (1930) *The Physical Principles of the Quantum Theory*, p.39

We have information or knowledge about the second electron's position, not because we are measuring it directly. We are *calculating* its position using the *principle* of the conservation of momentum.

This metaphysical information analysis will be our basis for explaining the EPR "paradox," which is actually not a paradox, because there is really no action-at-a-distance in the sense of matter or energy or even information *moving* from one place to another! It might better be called "*knowledge-at-a-distance*."

Einstein and his colleagues hoped to show that quantum theory could not describe certain intuitive "elements of reality" and thus is *incomplete*. They said that, as far as it goes, quantum mechanics is correct, just not "complete." Einstein was correct that quantum theory is "incomplete" relative to classical physics, which has twice as many dynamical variables that can be known with arbitrary precision. The "complete" information of classical physics gives us the instantaneous position and momentum of every particle in space and time, so we have complete path information. Quantum mechanics does not give us that path information.

For Niels Bohr and others to deny the incompleteness of quantum mechanics was to play word games, which infuriated Einstein.

Einstein was also correct that indeterminacy makes quantum theory an irreducibly discontinuous and statistical theory. Its predictions and highly accurate experimental results are statistical in that they depend on an ensemble of identical experiments, not on any individual experiment. Einstein wanted physics to be a continuous field theory like relativity, in which all physical variables are completely and locally determined by the four-dimensional field of space-time in his theories of relativity. In classical physics we can have complete path information. In quantum physics we cannot.

## Visualizing Entanglement

Erwin Schrödinger said that his "wave mechanics" provided more "visualizability" (*Anschaulichkeit*) than the "damned quantum jumps" of the Copenhagen school, as he called them. He was right. We can use his wave function to visualize EPR.

But we must focus on the probability amplitude wave function of the "entangled" two-particle state. We must not attempt to describe the paths or locations of independent particles - at least until after some measurement has been made. We must also keep in mind the conservation laws that Einstein used to describe nonlocal behavior in the first place. Then we can see that the "mystery" of nonlocality for two particles is primarily the same mystery as the single-particle collapse of the wave function. But there is an extra mystery, one we might call an "enigma," that results from the *nonseparability* of identical indistinguishable particles.

Richard Feynman said there is only one mystery in quantum mechanics (the superposition of multiple states, the probabilities of collapse into one state, and the consequent statistical outcomes).

> "We choose to examine a phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery. We cannot make the mystery go away by "explaining" how it works. We will just tell you how it works. In telling you how it works we will have told you about the basic peculiarities of all quantum mechanics." [4]



The additional enigma in two-particle nonlocality is that two indistinguishable and nonseparable particles appear simultaneously (in their original interaction frame) when their joint wave function "collapses." There are two particles but only one wave function.

In the time evolution of an entangled two-particle state according to the Schrödinger equation, we can visualize it - as we visualize the single-particle wave function - as collapsing when a measurement is made. Probabilities go to zero except at the particles' two locations.

Quantum theory describes the two electrons as in a superposition of electron spin up states ( + ) and spin down states ( - ),

$| \psi > = 1/\sqrt{2}) \,| + - > - 1/\sqrt{2}) \,| - + >$

What this means is that when we square the probability amplitude there is a 1/2 chance electron 1 is spin up and electron 2 is spin down. It is equally probable that 1 is down and 2 is up. We simply cannot know. The discontinuous "quantum jump" is also described as the "reduction of the wave packet." This is apt in the two-particle

4 Feynman (1964) *The Feynman Lectures on Physics*, vol III, p.1-1

case, where the superposition of | + - > and | - + > states is "projected" or "reduced" by a measurement into one of these states, e.g., | + - >, and then further reduced - or "*disentangled*" - to the product of independent one-particle states | + > | - >.

In the two-particle case (instead of just one particle making an appearance), when either particle is measured, we know instantly the now determinate properties of the other particle needed to satisfy the conservation laws, including its location equidistant from, but on the opposite side of, the source. But now we must also satisfy another conservation law, that of the total electron spin.

It is another case of "knowledge-at-a-distance," now about spin. If we measure electron 1 to have spin up, the conservation of electron spin requires that electron 2 have spin down, and instantly.

Just as we do not know their paths and positions of the electron before a measurement, we don't know their spins. But once we know one spin, we instantly know the other. And it is not that anything moved from one particle to "influence" the other.

## Can Metaphysics Disentangle the EPR Paradox?

Yes, if the metaphysicist pays careful attention to the information available from moment to moment in space and time. When the EPR experiment starts, the prepared state of the two particles includes the fact that the total linear momentum and the total angular momentum (including electron spin) are zero. This must remain true after the experiment to satisfy conservation laws. These laws are the consequence of extremely deep properties of nature that arise from simple considerations of symmetry.

Physicists regard these laws as "cosmological principles." For the metaphysicist, these laws are metaphysical truths that arise from considerations of symmetry alone. Physical laws do not depend on the absolute place and time of experiments, nor their particular direction in space. Conservation of linear momentum depends on the translation invariance of physical systems, conservation of energy the independence of time, and conservation of angular momentum the invariance of experiments under rotations.

A metaphysicist can see that in his zeal to attack quantum mechanics, Einstein may have introduced an asymmetry into the EPR experiment that simply does not exist. Removing that asymmetry completely resolves any paradox and any conflict between quantum mechanics and special relativity.

To clearly see Einstein's false asymmetry, remember that a "collapse" of a wave function just changes probabilities everywhere into certainties. For a two-particle wave function, any measurement produces information about the particles' two new locations instantaneously. The possibilities of being anywhere that violate conservation principles vanish instantly.

At the moment one electron is located, the other is also located. At that moment, one electron appears in a spacelike separation from the other electron and a causal relation is no longer possible between them. Before the measurement, we know nothing about their positions. Either might have been "here" and the other "there." Immediately after the measurement, they are separated, we know where both are and no communication between them is possible.



Let's focus on Einstein's introduction of the asymmetry in his narrative that isn't there in the physics. It's a great example of going beyond the logic and the language to the underlying information we need to solve both philosophical and physical problems.

Just look at any introduction to the problem of entanglement and nonlocal behavior of two particles. It always starts with something like "We first measure the first particle and then..."

Here is Einstein in his 1949 autobiography...

> "There is to be a system which at the time t of our observation consists of two partial systems $S_1$ and $S_2$, which at this time are spatially separated and (in the sense of the classical physics) are without significant reciprocity. [Such systems are not entangled!]
>
> All quantum theoreticians now agree upon the following: If I make a complete measurement of $S_1$, I get from the results of the measurement and from $\psi_{12}$ an entirely definite $\psi$-function $\psi_2$ of the system $S_2$... 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." [5]

5 Einstein (1949) 'Autobiographical Notes,' *Albert Einstein: Philosopher-Scientist*, Ed. P. A. Schilpp, 1949, p.1, in German and English

But two *entangled* particles are not separable before the measurement. No matter how far apart they may appear *after* the measurement, they are inseparable as long as they are described by a single two-particle wave function $\psi_{12}$ that cannot be the product of two single-particle wave functions. As Schrödinger made clear to Einstein in late 1935, they are only separable *after* they have become *disentangled*, by some interaction with the environment. If $\psi_{12}$ has decohered, it can then be represented by the product of independent ψ-functions $\psi_1 * \psi_2$, and then what Einstein says about independent systems $S_1$ and $S_2$ would be entirely correct.

Schrödinger more than once told Einstein these facts about entanglement, but Einstein appears never to have absorbed them.

A proof that neither particle can be measured without instantly determining the other's position is seen by noting that a spaceship moving at high speed from the left sees particle 1 measured before particle 2. A spaceship moving in the opposite direction reverses the time order of the measurements. These two views expose the false asymmetries of assuming either measurement can be made prior to the other. In the *special frame* that is at rest with respect to the center of mass of the particles, the "two" measurements are simultaneous, because there is actually only one measurement "collapsing" the two-particle wave function.



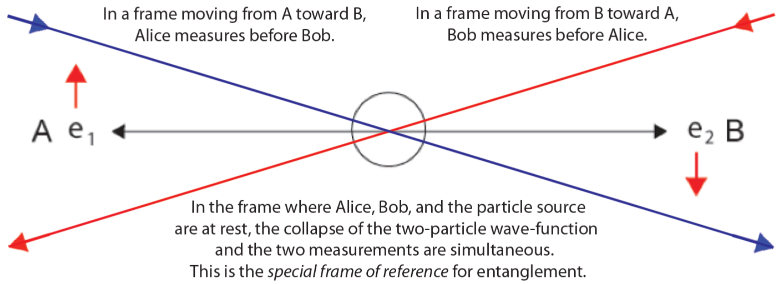


**Figure 25-4.** The special frame in which the two particles appear time symmetrically is the rest frame of the experiment.

Any measurement collapsing the entangled two-particle wave function affects the two particles instantly and symmetrically. We hope that philosophers and metaphysicians who pride themselves as critical thinkers will be able to explain these information and symmetry implications to physicists who have been tied in knots for so many decades by Einstein's introduction of an unreal asymmetry into the EPR paradox and entanglement.