CAUSAL IMPLICATIONS OF THE VERIFICATION OF BELL'S THEOREM

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In 1982, Aspect, at the University of Paris, performed an experiment which successfully demonstrated the truth of the assertion of Bell's theorem that causal locality does not obtain.[1] That is, Aspect was able to construct an experiment in which a causal effect was observed to operate at a distance. News of this hardly made national headlines, but the consequences of the empirical verification of the Einstein-Podolsky-Rosen Gedanken (EPR) has profound implications for any theory of causality and should have caused more consternation than it did.

The actual experiment involved the use of polarized light. However, as philosophers are traditionally uncomfortable with elaborate technology, we will examine the problem in terms of the more familiar Heisenbergian uncertainty concerning the velocity and position of a particle. The theorem applies equally well to any quantum phenomena with two complimentary functions. The polarization of light is merely more amenable to experimental procedures.[2]

As we all know, it is not possible, according to quantum mechanics, to measure both the position and velocity of a sub-atomic particle. The measuring of one variable hopelessly distorts the other. However, if one had two particles which were moving at the same velocity through parallel positions, it would seem that one could measure the velocity of one and the position of the other. As such sub-atomic particles exist, emitted by certain sorts of excited atoms, a Gedanken of this sort has been considered for some time.[3]

We can understand this Gedanken better by considering an analogous situation. Let us consider a pool table with two balls side by side and a cue ball directly in front of them. We hire a great master pool player, say "Fast Eddie," to strike the cue ball so that both balls roll off at a 90^{o} angle from each other at the same velocity. We then measure the position of one of the balls, thus altering the direction of its movement, i.e., its position.

Imagine our horror if, while doing this, we observed that at the same time, the direction of the unmeasured ball was changed and swerved in the same way the measured ball did. It would be

almost as if, in the middle of a game of pool, when the nine ball was sunk, the eight ball suddenly decided to fall into a pocket on its own with no help from the players. Such a swerve of the unmeasured particle is essentially the result of the first experiment which attempted to verify (or as a matter of fact, disconfirm) Bell's theorem, an experiment performed by Clauser in 1972.[4] It was found that measuring the polarization of one photon influenced the polarization of another photon emitted at the same time as the first, but thereafter apparently causally independent.

Naturally, attempts have been made to explain this result in some "reasonable" fashion. The first suggestion made was that in some way information is being transferred from one particle to another. To extend our pool playing analogy, we might claim that tiny radio transmitters and receivers had been embedded in the balls and when one ball's path was influenced, the other ball was directed to also change its path. This solution, however, would require, within the context of Clauser's experiment, that the information be transmitted faster than the speed of light.[5] If such an event were allowed, not only would the speed of light constant be violated, since information must have a material carrier, but we would also be faced with the possibility of tachyons and therefore with the possibility of negative time. This is an even more serious problem for causality than the problem we are considering, as the analyses of Grunbaum[7] on the effects of time reversal show. While the causal theory that all the universe forms one causal unit and there is no causal locality is counter-intuitive, the reversing of time produces causal theories with actual paradoxes, such as things being caused by events which follow the causal event. One thus has "bootstrapping" paradoxes in which an event and its cause become a "closed loop" with no clear beginning.

The other loophole proposed to avoid Bell's theorem is the suggestion that some "hidden variable" of which we are unaware operated at the beginning of the experiment and influenced the paths of both particles. To return to our analogy, we might suspect that "Fast Eddie," who is after all not a terribly reliable character, made his break so as to cause the swerves observed. It was this loophole which Aspect's experiment closed. The current technology is such that it is possible to start the measurement process only after the photons are emitted, rather than as if we only decided what to measure after "Fast Eddie's" break.

There seems to be no way to avoid the conclusion that Bell's theorem has been empirically verified,[8] and observing one member of a linked pair of photons after they have been separated influences the behavior of the other. This is uncomfortably reminiscent of contagious magic, in which two objects, once associated, continue to influence each other at a distance. Causal effects are no longer limited to events in the locality of the object.

All this seems to suggest that perhaps my poking pins in a doll *will* give you a stomachache.

The careful thinker might object that this move from photons to voodoo, from the laboratory to the real world, is unjustified. However, since all the particles in the universe were emitted at the same time in the big bang, within the terms of this experiment, all the particles in the universe are linked.[9] Causally, the universe forms a single whole and causal effects can occur simultaneously, in an unmediated fashion, at a distance. This clearly violates not only our common sense understanding of causality but also the majority of the standard theories of causation. A theory which can consider the possibility that my scratching my ear will cause a person in Calcutta to sneeze seems more a part of the mysticisms of Casteñeda than the theories of serious philosophy and physics.

We could, of course, push the hidden variable back in time to the big bang. This would produce a sort of pre-established harmony with the singularities of the big bang operating instead of the deity to preset the two photons to behave as they did. This, however, requires, as any pre-established harmony must, a strict determinism. Thus, not only are the paths of the two photons determined by the singularities of the big bang; Aspect's experiment, its date, the place it was performed, and even Aspect's existence must also be determined by the big bang. Besides the inherent unpalatability of quantum mechanics resulting in total determinism, such a solution is totally incapable of verification and thus to a physicist presents no solution at all.[10] Only a few diehards in physics are satisified by hidden variables which are in principle undiscoverable.[11]

What sort of causal theory are we therefore forced to accept if we are unwilling to have the paradoxes of time travel or the determinism of a pre-established harmony? It is one in which the possibility of isolated causal chains can no longer be assumed to obtain; one in which the action of one particle may exert a causal effect on a particle at some distance from the first.

As philosophers, we must at this point ask how it is that we have failed to observe this situation heretofore. If, in some sense, contagious magic works, why haven't we been aware of this fact? There are two reasons for this.

First, the operation of this phenomenon is likely to be extremely complex. Consider the problem of discovering which particles were influenced by the same singularities in the big bang. The patterns of causation would be so far flung as to appear the actions of random chance.

Second, the phenomenon we are considering is essentially statistical in nature. To actually cause that hypothetical person in Calcutta to sneeze, I must influence a great many particles within his body. Each of these particles has a different causal relationship

to the great number of particles in my body which alter when I scratch my ear. Most such influences must get lost in the "noise" of the system. It might, for example, be only twenty sub-atomic particles whose behavior is changed. However, that is only a tiny fraction of even one blood cell, even assuming that these particles were all to be found in one coherent system of the body. The likelihood of enough particles being influenced to make a macroscopic difference is minimal. Just as quantum mechanics asserts that the predicability of a system is uncertain at the sub-atomic level (due to the Heisenberg Principle), but systems become predictable at the macroscopic level due to the cascading of probabilities, so while causation at the sub-atomic level is non-local, at the microscopic level I must still be next to you to push you over.

This is not to say that this problem is all merely of theoretical interest. The transfer of information can involve only a few particles. From this, ways have been suggested for making use of this principle in technology and it has suggested that a model for things such as ESP could possibly be developed from this idea.[12] In general, however, this experimental result has much the same effect on philosophy that quantum mechanics usually has. It alters our way of seeing old problems. Just as Heisenberg has altered our understanding of prediction, so Bell and Aspect have forever changed the way we can look at cause.

Notes

1 Alain Aspect, Jean Dalibard, and Gerard Roger, "Experimental Test of Bell's Inequalities Using Time-varying Analyzers," *Physical Review Letters* 49 (1982): 1804.

2 John Gribbin, *In Search of Schrodinger's Cat* (New York: Bantam, 1984) 218.

3 Paul Davies, *Superforce: The Search for a Grand Unified Theory of Nature* (New York: Simon, 1984) 43-45.

4 John F. Clauser and Abner Shimony, "Bell's Theorem: Experimental Tests and Implications," *Reports on Progress in Physics* 41 (1978): 1881.

5 Nick Herbert, *Quantum Reality: Beyond the New Physics* (Garden City: Anchor/Doubleday, 1985) 214.

6 Gribbin 226.

7 Adolf Grunbaum, *Philosophical Problems of Space and Time* (New York: Knopf, 1963).

8 N. David Mermin, "Is the Moon There When Nobody Looks: Reality and the Quantum Theory, *Physics Today* April

1985: 40.

[9] Herbert 223.

[10] At least in conversations with physicists, this appears to be their main concern.

[11] Gribbin 228.

[12] Fred Alan Wolf, *Taking the Quantum Leap* (Cambridge: Harper, 1981) 207-215 and Gribbin 231-232.