Quantum Baseball

A baseball analogy illuminates a paradox of quantum mechanics

By IVARS PETERSON

N. David Mermin is a physicist with a philosophical bent and a passion for baseball. From Cornell University in Ithaca, N.Y., he follows the fortunes and antics of the New York Mets while pondering the meaning of puzzling experiments involving photons of light. Perhaps inevitably, he sees a link between quantum mechanics and baseball.

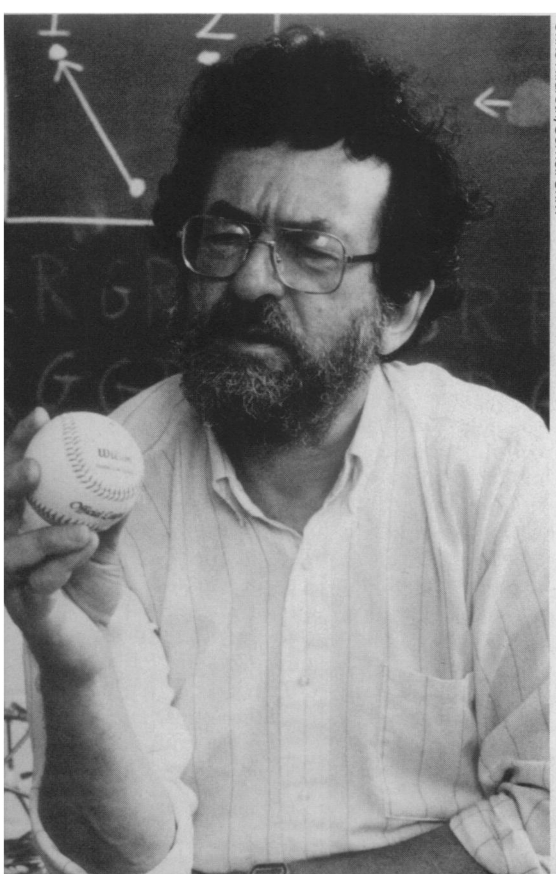
Mermin's ruminations put him in the middle of a long-standing debate about the nature and meaning of quantum mechanics – the modern, remarkably successful theory of the atomic world. He uses the language of baseball to illustrate how everyday ideas and intuitions fail when confronted by the extraordinarily strange realm of quantum mechanics.

Mermin's immediate concern is a hypothetical situation first proposed in 1935 by Albert Einstein, Boris Podolsky and Nathan Rosen as an argument against quantum theory. Suppose a single process within an atom generates two photons of light. The two photons, traveling in opposite directions, are called correlated because they come from the same place at the same time.

According to quantum theory, neither of these photons has a well-defined polarization, or orientation, until it's measured at a detector. In effect, the act of measuring transforms the photon from one whose polarization is just a set of probabilities to one with a particular polarization. The surprise is that measuring just photon A's polarization means that photon B also acquires a polarization.

Einstein and his collaborators argued that if measuring the polarization of photon A at one end of a room would automatically tell them photon B's polarization, then B's state is known without requiring an act of measurement. Otherwise, one must suppose that the measurement of A's polarization instantaneously affects its partner at the other end of the room and forces B into the appropriate state.

The first choice implies that quantum theory ought to be reworked to include the possibility that quantum-mechanical objects have inherent, objective attributes that don't depend on the act of measurement. The second choice provides physics with what Einstein called "spooky" actions at a distance. Physicists generally don't like the idea of one thing influencing another without some physical connection, such as a piece of cord, a light beam or a radio wave, between them.


Chris Hildreth/Cornell Univ.

Physicist N. David Mermin uses a baseball analogy to illustrate the strangeness of quantum mechanics.

The most illuminating test of the Einstein-Podolsky-Rosen correlations occurred in a series of experiments in 1981 and 1982 by Alain Aspect of the University of Paris-South in Orsay and his collaborators. They studied a large number of two-photon emissions from calcium atoms by setting up polarizers at opposite ends of a room, independently and randomly changing the polarizer settings between emissions and observing how many photons managed to get through instead of being absorbed. The statistics of the results confirmed the spooky behavior of photons—forcing one into a given state forces the other (SN: 1/11/86, p.28).

To get a better sense of what the Aspect experiments mean, Mermin has invented a thought experiment to reveal in an elementary way how perplexing the experimental data are. "For me, the philosophical issue I'm trying to illustrate is best exemplified by thinking about baseball," Mermin said at an American Physical Society meeting earlier this year.

True baseball fans feel deep inside that their watching a game on TV really does influence the game. But, forced to be rational, most fans realize that whether they watch a game on TV has no effect on the game's outcome. "What I do or don't do in Ithaca, N.Y., will have no effect on what the Mets do or don't do in Flushing, N.Y.," Mermin says. "I call this the Baseball Principle. You can't help the Mets by watching them on TV."

Expressed as a statistical statement about many baseball games, this principle is easy to check. If you examined the results of a large number of Mets games, you would find that the team was no more or less successful in the games Mermin watched than in those he didn't watch.

The rational baseball fan, despite powerful, contrary emotions, also knows that the Baseball Principle applies to individual games as well. The outcome of a particular game doesn't depend on whether or not the fan watches the game on TV. But a professional philosopher would argue that applying the Baseball Principle to an individual game is nonsense.

"Either you watch it or you don't," the philosopher says. "So you can't check the principle by comparing what happened when you did watch it with what happened when you didn't." In other words, the Baseball Principle has no meaning when applied to individual games because there is no way to verify it. An individual game can't be both watched and not watched.

"But is it really wrong, rather than merely silly, to apply the Baseball Principle to an individual game?" Mermin asks. "Let us call the claim that the Baseball Principle applies to each individual game the Strong Baseball Principle," he says. "As a rational person who is not superstitious and does not believe in telepathy or the efficacy of prayer on the sporting scene, I'm convinced that the Strong Baseball Principle is true."

However, Aspect's photon correlation experiments show that the philosopher and the baseball fan are both wrong. "The philosopher is wrong because there is a way to check, and the rational baseball fan is wrong because the check reveals that you cannot apply the Baseball Principle to individual games," Mermin says.

In Mermin's interpretation of Aspect's experiment, an emitter of pairs of correlated photons sits between two detectors, A and B, located at opposite ends of a room. The detectors flash red or green, depending on whether a photon stops or gets through. Both detectors also have two possible settings that determine the angles at which polarization readings are made. The choice of setting at one detector corresponds to a fan's decision to watch or not watch a game, and the color flashed at the other detector corresponds to the game's outcome.

Suppose detector A has settings labeled 1 and 3, and B has settings labeled 2 and 4. It's possible to orient the polarizers so that for the setting combinations of A1-B2, A3-B2 and A3-B4, the two detectors flash the same color 85 percent of the time. If the setting combination is A1-B4, the detectors agree only 15 percent of the time.

"First of all, you can verify that the Baseball Principle holds," Mermin says. For a large number of runs (for example, with detector A set at 3 and B set at 2), one sees a random string of greens and reds, each color occurring about half the time. The same thing happens when A is set to 1. "The character of the data at B doesn't depend on how the polarizer is set at A, or vice versa," he concludes.

The Strong Baseball Principle implies that for individual pairs of photons, what happens at one detector doesn't depend on the choice of setting at the other detector. "It's reasonable to assert that whatever would have happened at B in a particular run when B was set to 2 and A was set to 3 would have been the same as what would have happened at B in that same run if B had been set to 2 and A had been set to 1," Mermin insists.

Consider many runs of an experiment in which B is set to 2 and A is set to 3, which might produce the following results in which colors (G stands for green and R for red) at the detectors agree about 85 percent of the time:

B2: G G G G R G R R R G G R G R R G G R R
A3: G G R G R G R R G G G R G R R G R R R.

According to the Strong Baseball Principle, the light at detector A would have flashed green in the first run of this sequence even if detector B had been set to 4. A similar argument applies to every run in the sequence. Thus, although no one can say what sequence of colors would have appeared at B if B had been set to 4, the sequence at A would have looked exactly the same. Similarly, if A had been set to 1, nothing would have changed at B:

A1: ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?
B2: G G G G R G R R R G G R G R R G G R R

A3: G G R G R G R R G G G R G R R G R R R
B4: ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

Although one doesn't know in detail what sequence of colors would have appeared if A had been set to 1 instead of 3, one does know that the colors appearing at A would have to agree with the colors at B 85 percent of the time (or disagree 15 percent of the time), just as the colors in the original experiment involving A3 and B2 agree 85 percent of the time. The same constraint holds for colors detected at B4 when A is set to 3.

"But now we're in big trouble," Mermin asserts. What does this say about what would happen if A had been set to 1 and B to 4?

The colors in the hypothetical A1-B4 experiment should agree 15 percent of the time (or disagree 85 percent of the time). But that's impossible because the colors flashed at both detectors in the hypothetical A3-B4 experiment disagree 15 percent of the time, the results of the real A3-B2 experiment disagree 15 percent of the time and the results of the hypothetical A1-B2 experiment disagree 15 percent of the time. If the Strong Baseball Principle were correct, the colors in the hypothetical A1-B4 experiment could therefore differ at most about 45 percent of the time.

"There are no conceivable data . . . that are consistent with the outcome at A being independent of the setting at B, and vice versa, run by run," Mermin says. "The Strong Baseball Principle is refuted not because it's meaningless but because it's wrong."

Mermin goes on: "These are intrinsically quantum-mechanical data, and the lesson from these data is . . . that you have to be extraordinarily careful in talking about what might have happened but didn't. In this case, the numbers demonstrate that there's no way you can make up a picture to account for what might have happened but didn't."

In conventional approaches to quantum mechanics, theorists can find apparently reasonable ways of accounting for correlations. But if you try to ask questions that quantum mechanics doesn't allow you to ask, then these apparently reasonable quantum-mechanical results start to seem unreasonable. "My guess is that somehow statistical analysis has embedded in it assumptions about what might have happened but didn't that have not in fact been sufficiently well explored," Mermin says. "In my new career as a philosopher, I'm hoping that I may get a chance to explore this further."

A vigorous debate on the meaning of quantum physics has recently spilled across the pages of PHYSICS TODAY. In the October 1988 issue, Herman Feshbach and Victor F. Weisskopf, both associated with the Massachusetts Institute of Technology, argue that the role of indeterminacy in quantum mechanics has been greatly exaggerated. Although probability plays an important role, they say, it doesn't follow that the predictions of quantum mechanics are necessarily uncertain. Furthermore, they contend there's nothing particularly mysterious about photon correlations.

Mermin replies in a commentary published in the April issue. In a classical, deterministic world, in which precise laws of physics govern every occurrence, you can calculate what would happen if you had done something different, he says. The Strong Baseball Principle has to be true in a deterministic world.

"Therefore, I'm happy to be told there's nothing mysterious about these correlations, *or* I'm happy to be told that the importance of indeterminism in quantum mechanics has been exaggerated," Mermin says. "But I'm not happy to be told *both.*"

He adds, "I would rather celebrate the strangeness of quantum theory than deny it, because I believe it still has interesting things to teach us about how certain powerful but flawed verbal and mental tools we once took for granted continue to infect our thinking in subtly hidden ways." □