"At least in this case, they've locked it down to an asymmetric structure," says biophysicist Ken van Holde at Oregon State University in Corvallis, but he and others point out that the structure may be a peculiarity of *Xenopus* nucleosomes. "I still have to be convinced there's just one binding site," adds Morton Bradbury, a structural biologist at the University of California, Davis, who notes that few results over the past 2 decades have contradicted the notion of two binding sites.

But if the new structure does prove to be widespread, it could support a new view of the role that the linker histones play in gene regulation—a role that is more complex than researchers have envisioned in the past. In their traditional position, outside the DNA spirals, the linker histones would act mainly to repress the activity of a large number of genes by blocking the access of regulatory proteins. But if the linker histones snuggle inside the DNA coils, they "may change the path of the DNA," notes Bradbury, which could make specific genes more accessible for transcription.

In keeping with this picture, Gorovsky and his colleague Xuetong Shen found signs that linker histones have both positive and negative effects on gene activity in a ciliated protozoan, *Tetrahymena thermophila*. These researchers eliminated the protozoan's linker histones, called H1 proteins, by knocking out the corresponding genes. They found that a gene known as *ngo-A*, expressed in normal *Tetrahymena* only during periods of starvation, was active all the time in the knockouts. That result fits in with the long-held view that linker histones slow down gene transcription.

But the loss of the H1 proteins had another, quite unexpected, effect on a gene called *CyP*. This gene codes for an enzyme involved in protein degradation. Like *ngo-A*, it becomes active during periods of starvation. But in starved knockouts, it was barely expressed at all. With these two findings, says Gorovsky, "we've clearly demonstrated that [the linker histone] can play a positive or negative role in gene expression."

The same is likely to be true of other linker histones, says Wolffe: "Far from being global repressors, [they] are quite specific in their effects." But not everyone is willing to make such sweeping statements. What Gorovsky sees "could well be a special case," says Bradbury, who points out that the *Tetrahymena* has unusual, shrunken linker histones that lack a globular domain altogether. "You've got to be careful about being too general."

Even at this stage, though, one thing is certain, says Gorovsky: The Byzantine bureaucracy of the chromosomes is looking even more intricate.

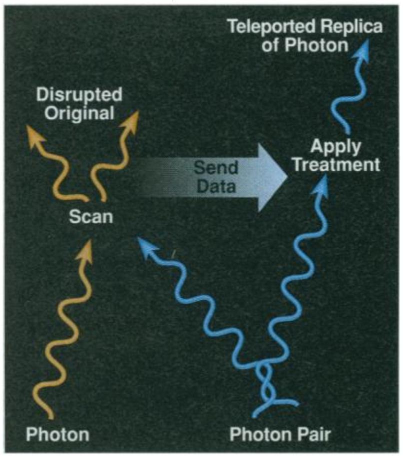
–Elizabeth Pennisi

QUANTUM MECHANICS

To Send Data, Physicists Resort to Quantum Voodoo

Tabloid journalists and writers of mystical self-help works will be happy to know there is an area of physics that holds a vague resemblance to voodoo. It involves one of the weirdest of quantum-mechanical paradoxes, in which two particles can be created simultaneously with their internal quantum states—their spin, for instance, or polarization—irrevocably "entangled." Quantum mechanics dictates that until a particular state is actually measured, it has no value at all. But when a measurement is made on one entangled particle, its partner instantly takes on the opposite value, even if it happens to be halfway across the universe at the time.

This is what Albert Einstein once referred to as "spooky action at a distance," and what Charles Bennett, an IBM fellow and renowned quantum mechanician, likens to voodoo. The entanglement establishes a unique connection between the two particles such that what Bennett calls the "quantum essence of the particle" passes from one to the other like a curse passing from a lock of hair back to its original owner. As quantum-mechanics researchers have shown lately, this quantum voodoo can be put to work in ways that are less maleficent but no less spooky, for transmitting data and even "teleporting" the quantum state of a particle, along with all the information it embodies.



Beam me over. In quantum teleportation, one entangled photon interacts with an unknown photon, yielding data that are transmitted to the other entangled photon to resurrect the unknown photon's quantum state.

Last June, for instance, physicists at the University of Innsbruck in Austria reported that they could convey one of three distinct "trits" of data through a single entangled photon, as opposed to the two binary bits that are all a photon can ordinarily handle. By the end of the year, the Innsbruck group hopes to use the same basic techniques to make the quantum state of a particle interacting with one entangled photon disappear, then reappear elsewhere in the other member of the entangled pair, without physically making the trip.

Weird as it all sounds, says Bennett, there is little suspense about these experiments. "We're almost certain what the results will be before we start, because everyone believes quantum mechanics," he says. Instead, there are practical reasons for attempting these feats. Teleportation, for instance, may play an important role in future computers based on quantum mechanics (*Science*, 7 July 1995, p. 28). And there's another kind of lure, says Bennett—the enticement of seeing the wildly counterintuitive predictions of quantum theory borne out.

Quantum voodoo of any kind starts with an entangled pair of photons. The Innsbruck physicists, led by Harald Weinfurter, produce them using a type of optical crystal that absorbs one high-energy, ultraviolet photon and emits in exchange two entangled low-energy photons. These photons are born with an irrevocable quantum link, which emerges, for example, when one of them passes through a polarized filter set at a particular angle. "The photons individually don't possess a definite polarization," says Los Alamos National Laboratory physicist Paul Kwiat, who works with the Innsbruck group, "and yet there's a definite polarization relationship between the two." If the filter is horizontally polarized, for instance, and one of the pair manages to pass through it, the other photon will instantly assume a vertical polarization.

The Innsbruck group has shown that they can exploit this relationship to get around the quantum-mechanical uncertainty principle, which ordinarily limits the amount of information that can be extracted from a single photon. While a photon's polarization, for example, can fall anywhere between 0° and 360° to infinite precision—so that in principle it can carry any of an infinite number of bits—the best any measurement can say is whether or not it will pass through a filter polarized at a particular angle. The result is one of two bits—a 0 or a 1. But by making joint measurements of an entangled photon and its partner, the Innsbruck group is able to do better.

They begin by sending one of the two entangled photons to a transmitter, which quantum mechanicians invariably refer to as "Bob." Bob encodes the photon with the three bits, the equivalent of a 0, 1, or 2, by either doing nothing to the photon (to encode a 0), rotating the polarity of the photon 90° (1), which can be done with something as simple as a quartz crystal, or giving the photon a polarization-dependent "phase shift" (2) by putting it through a special material that delays its wave. None of these operations constitutes a measurement, so by the rules of quantum mechanics the states of both entangled photons remain undetermined.

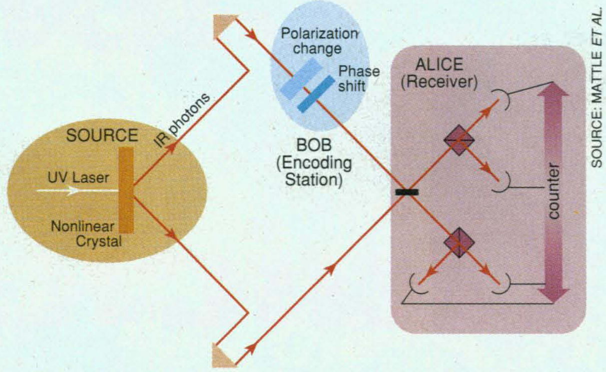
Nevertheless, each operation leaves the quantum state of the entangled pair in a different configuration. Doing nothing means the two photons will still have opposite polarizations. Rotating the polarization of Bob's photon 90° means the two will now have the same polarization. And shifting the phase of Bob's photon means they will have opposite polarizations and opposite phases. The photons are still entangled, but a measurement will now reveal a different relation between their states.

Bob then sends his photon onto the receiver, known in this business as "Alice." If Bob's photon did not have an entangled partner, Alice would be able to obtain only one of two bits of information from it. But because of the magic of entanglement, the three bits Bob encoded are actually embodied in two photons rather than one, where they can be extracted by performing a joint measurement. The second photon arrives at Alice at the same time as its encoded partner, and Alice compares them by passing them through a series of beam splitters, which are filtered mirrors that divert photons in different directions depending on their phase or polarization.

The setup can distinguish the three different possibilities with what Weinfurter calls "pretty good efficiency and high reliability." While Bob can theoretically encode a fourth state in his photon by changing both its polarization and its phase, the Innsbruck detectors were not able to distinguish that state from one in which only the polarization was changed.

Even at three bits per photon, says physicist Daniel Greenberger of the City College of New York, the demonstration shows "that quantum-mechanical communication is in a sense superior to classical communication." He concedes, however, that it is basically a "toy" demonstration: Although the transmitter can encode three bits of information by manipulating a single photon, it still takes two photons to complete the transmission. But Weinfurter notes that the techniques used in quantum communication for encoding and decoding the messages are necessary ingredients for quantum teleportation, where what is communicated is the essence of an entire photon, along with the infinite—albeit largely inaccessible—information it contains.

The idea was conceived in 1992 in discussions among half a dozen quantum mechanicians at a meeting in Montreal. In the scheme, the entangled pair of photons is split between transmitter and receiver, just as in quantum communication. But this time, it's the transmitter—Bob, again—that does the joint measurement, in this case comparing his entangled photon with a third photon that is to be teleported. Bob draws one of the four possible conclusions about their relative polarizations and phases allowed by the uncertainty principle.



Alice gets the message. In a laser-driven apparatus, the transmitter (Bob) takes advantage of entangled photon states to send one of three different data bits by manipulating a single photon.

Next, Los Alamos's Kwiat explains, "[Bob] calls up Alice on the telephone, or through some other means, and tells her which of four results he got." Alice then puts her member of the entangled pair through the same polarity and phase transformations used to encode a message in quantum communication. For instance, if Bob's result is a 0, Alice does nothing to her entangled photon; if it's a 1, she rotates the polarity 90°, and so on. "If she does that," says Kwiat, "then the photon she ends up with will be in exactly the same state as the one that Bob was trying to teleport."

To understand why that's so, says Kwiat, imagine the simplest case: Bob finds that the unknown photon and his entangled photon have opposite polarizations. This is the 0 state, in which Alice then does nothing to her photon. But because Alice's photon is by definition opposite to Bob's, its entangled partner, it has to have the same polarization as the unknown photon. "So she just leaves hers as it is," says Kwiat. "The other ones are more difficult to explain, but from the math it's very clear it works out."

More peculiar, Kwiat says, is the fact that Bob's measurement collapses the state of the original photon together with his entangled photon to a single value—yet Alice can resurrect the entire quantum state of that unknown photon. "The amazing thing is when Bob telephones Alice and tells her which state he measured," says Kwiat, "and she does one of her four operations, her entangled photon regains the infinite amount of information of the unknown photon. It's, well ... it's been teleported. It's completely true that you can't access that information by any known measurements." But the mathematics insist that "it really is there."

Quantum teleportation requires distinguishing all four states and manipulating photons with exquisite timing, but it is now "in the realm of being doable," says Sam Braunstein of Germany's University of Ulm. And if it works, it may prove remarkably useful, says IBM's Bennett. As other researchers work to harness quantum mechanics for computation and cryptography, teleportation could become the equivalent of a quantum mail service—a generic means of "transferring quantum information to a place where it's more convenient than the place where it originally arises."

The same thing could be done conventionally, by sending the original photon through space, but that would risk disturbing it. Says Bill Wootters of Williams College in Williamstown, Massachusetts, one of the originators of the scheme, "If you want to get some delicate quantum information from one part of a quantum computer to another part, it might be safer to try to teleport it directly than to somehow move it along a path from here to there."

Still, as Kwiat says, the main reason for doing these experiments now is to gain some intuitive understanding of phenomena that can be predicted by thought experiments but not necessarily grasped. "Everyone has some intuition about baseball and billiard balls," he says, which is invaluable for engineering mechanical devices. "But very few people have intuition about these quantum-mechanical interference and information effects. And the only way to make anything useful with them is if we really do have that good intuition."

–Gary Taubes