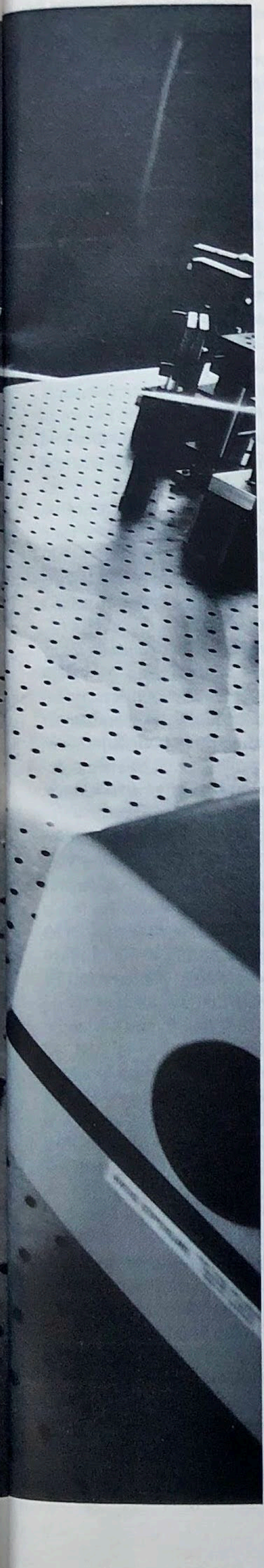


Les Boschke Photography

At the atomic level, all matter and radiation fluctuate in a random manner.

Ever since the advent of quantum physics, scientists have believed that this randomness places a limit on how precise they can be in understanding events. The position and momentum of a particle of light, for instance, cannot both be known at the same time.

Until 20 years ago, it was generally assumed that this randomness, which physicists call the Heisenberg Uncertainty Principle, was an absolute limit on human precision. When scientists tried to make very precise measurements of light, they would eventually reach a "noise" floor and would have to settle for that. In fiber optics, for instance, they could engineer away every possible interference and still be stuck with the "noise" of randomness.

Quantum Leap

Horace Yuen squeezes the uncertainty out of light.

By Chris Chandler

In 1975 Northwestern professor Horace Yuen, then a young research scientist in electrical engineering at the Massachusetts Institute of Technology, submitted a paper to *Physical Review* in which he proposed a way to get around this noise factor. You might not be able to measure both the location and the momentum of a particle of light, he wrote, but you could measure one of those dualities very precisely, at the expense of creating more uncertainty with the other.

There was nothing especially new about this idea, he wrote, since the founders of quantum physics had written about "conjugate," or interrelated, variables. For instance, the more you detect momentum, the less sure you will be of location. The more sure you are of the magnetic field, the less sure you will be of the electrical field.

On the other hand, the paper noted, such a possibility had not been considered by people in laser research, many of whom assumed they had to deal with equally divided variables.

After more than a year's delay and some strong disagreement from the paper's referees, *Physical Review* finally published the paper. In 1979 Yuen co-authored a second paper that proposed a method to manipulate laser light in such a way that a portion of the light waves would become more predictable; that more predictable portion could be used to make measurements or carry out communications functions. This is now called "squeezing light." Six years later, in 1985, a team at AT&T Bell Labs actually observed the light-squeezing effect.

Willis Lamb, Nobel Prize winning physicist then at Yale, strongly disagreed with Yuen's original proposal. He wrote a detailed analysis of why Yuen was wrong for the National Science Foundation, which denied Yuen funding for further research in 1979. But he has changed his position now.

"I'm afraid I have to admit I didn't believe it then," he said in a telephone interview from the University of Arizona's

Optical Science Center. "I've seen more light now so I believe it now."

In November 1990, 29 papers on squeezed light were presented at the annual meeting of the Optical Society of America. Bernard Yurke, who was on the AT&T team that first successfully observed squeezing, reported to the conference on the first successful squeezing of microwaves.

"Squeezed light has broken down barriers," he said in an interview. "We used to think there was a shot noise floor, an absolute limit to how precise we could be. Now we have ways to get around those limits."

Speakers at the conference described how squeezing light is being used to develop more accurate laser gyroscopes (at MIT) and to detect sound waves (at Northwestern) and nerve impulses (at AT&T Bell Labs). Research groups in Japan, Germany, France, New Zealand, and Australia are working on projects, ranging from optical computing applications to experiments looking more deeply into the nature of quantum physics. No one in the field any longer doubts that squeezed light will have a major impact on the science and technology of the 21st century.

MIT's Ray Weiss, who reported to the conference on the use of squeezed light in gravity wave detection, knew Yuen back in the early, difficult days at MIT. "The electrical engineering department didn't understand what he was talking about," Weiss recalls, "and the physics department wasn't interested. He fought a lonely, singular battle."

Yuen, a professor at Northwestern since 1980, in many ways continues to fight that lonely, singular battle. A boyish-looking 44-year-old professor of electrical engineering and computer science and physics and astronomy, he spends most of his time working alone at his kitchen table in his Glenview, Ill., home. Prem Kumar, associate professor of electrical engineering and Yuen's closest collaborator at Northwestern, says he sees him about once a month.

Yuen was born in Hong Kong but is an American citizen and feels few ties to his birthplace. His one passion, aside from physics, is ballroom dancing. He has studied dance at Arthur Murray studios and dances several times a week. He holds occasional dance parties in his home, and he dances with all the pride and precision that he gives to his work. "I learn something about myself. I can express myself," he says. But he is a little concerned that so few intellectual women dance.

He devotes most of his time to trying to solve what he calls "the quantum puzzle."

Quantum physics originated in 1900 when German physicist Max Planck was trying to explain why a heated metal would emit light when enclosed in a totally dark room. He proposed that radiation, until then thought of as a continuous field, could be divided into "quanta"—small quantities of energy that interacted with each other.

Albert Einstein took a major step in the development of quantum physics when he proposed in 1905 that light could be divided into tiny packets of energy, later called photons. His later work describing how photons were emitted by atoms under certain conditions led directly to the development of the laser, where a chain reaction of photons is touched off.

By 1920, quantum physics had become a comprehensive system capable of making accurate predictions of the overall behavior of subatomic particles. The behavior is seen as random, predictable only in terms of probabilities. For instance, we will never be able to know both the position and momentum of a particle, as we are used to thinking in the everyday world. We will never know when a photon will be

Squeezed Light to Guide Planes

The latest laser-based gyroscope can now guide a plane on automatic pilot from Los Angeles, Calif., to Chicago and allow it to land within a half-mile of O'Hare International Airport.

A new technology under development can theoretically increase that accuracy to within a quarter of a mile, and researchers say within five years they should be able to land the plane precisely on the landing strip.

The new technology is based on "squeezed light," a means of getting around what was once thought to be the irreducible "noise" factor in light. Laser gyroscopes may well be the first practical application for the scientific breakthrough pioneered by a Northwestern professor of electrical engineering, Horace Yuen.

Hermann A. Haus of the Massachusetts Institute of Technology has achieved a 60 percent reduction in quantum noise in a laser gyroscope, presumably making it possible for new gyroscopes to be that much more accurate, since they already are operating very close to the quantum noise limit. He is working with a U.S. and a Japanese electronics firm in the research.

Engineers at Litton Industries say its latest model gyroscopes can guide planes from Los Angeles to Chicago with an accuracy of just under a nautical half-mile. With a system using updates from satellites, the accuracy is improved to within 60 feet. Theoretically, both of those distances could be more than halved with Haus' quantum noise reduction, they acknowledge.

Other applications for squeezed light under development include increasing the accuracy of microscopic photos of nerve impulses, the sensitivity of sound wave detection at the atomic level, and the capacity of optical computing. Yuen believes it will eventually be applied to fiber optics communications.—*C.C.*

Horace Yuen devotes most of his time to trying to solve the "quantum puzzle."

emitted, or which atom will emit it, only the probabilities of emissions, it contends. Einstein strongly objected to this view, arguing that there must be an underlying reality. He said he would never accept a "God who plays dice."

A simple experiment shows the strangeness of behavior at the subatomic level. If you shoot a stream of photons across two holes in a barrier, the pattern that emerges behind the barrier looks as though the photons must be waves. But if you put detectors at the holes, the photons make two patches behind the holes, as if they were particles. Did the detectors interfere with the process, or does the act of observation itself change the outcome?

Dick Slusher at AT&T Bell Labs headed the research team that first observed a squeezed state of light in 1985 and is considered a leading authority in the field. He chaired several sessions at the November conference and is interested in using squeezing techniques for nerve impulse detection.

He says Yuen has written three classic papers in the field. The first, of course, in 1976. The second, co-authored with Jeffrey Shapiro, was "the one that got me into the field," Slusher says. The third, co-authored with MIT's Vincent Chan and printed in *Optics Letters* in March 1983, describes how the observed noise in a laser beam is purely a result of the quantum fluctuation of the beam itself, and had nothing to do with the detector.

"I thought it was all wrong and insane," Slusher recalls. "But it turned out he was right."

Slusher, like a great number of researchers in the squeezed light field, is fascinated with the possibilities that squeezing opens up to test the basic hypotheses of quantum physics. He is currently working on a version of one of the oldest quantum puzzles, called "Schrödinger's Cat."

In fact, researchers in at least four other locations are using Yuen's squeezing techniques to work on versions of "Bell's Inequalities," another puzzle that purports to prove either that there is no such thing as objective reality or that there must be instantaneous communication between particles at any distance.

Standard quantum physics theory is full of such weirdness. Theorists talk about photons moving backward in time, of their being nothing but probabilities until an observation is made, which for some becomes like a throwback to the old Gnostic view that reality is generated by human perception.

But Yuen, typically, stands outside this whole field. On the one hand, he is critical of the great number of physicists who "just don't understand standard quantum physics." On the other, he has no use for the quantum theory experiments, which he believes have a series of built-in flaws. For instance, photons acting in an unusual way is not proof of instantaneous communication through space, what Einstein derided as the notion of "telepathy."

In fact Yuen is one of the very few practicing quantum physicists who side with Einstein against the theorists of quantum physics. He believes there is an underlying reality that quantum physics only approximates, and it is his major goal to try to illuminate that underlying reality.

"Most physicists want to reconcile quantum physics and relativity," he says. "But quantum physics has to be modified itself before we can carry out that reconciliation."

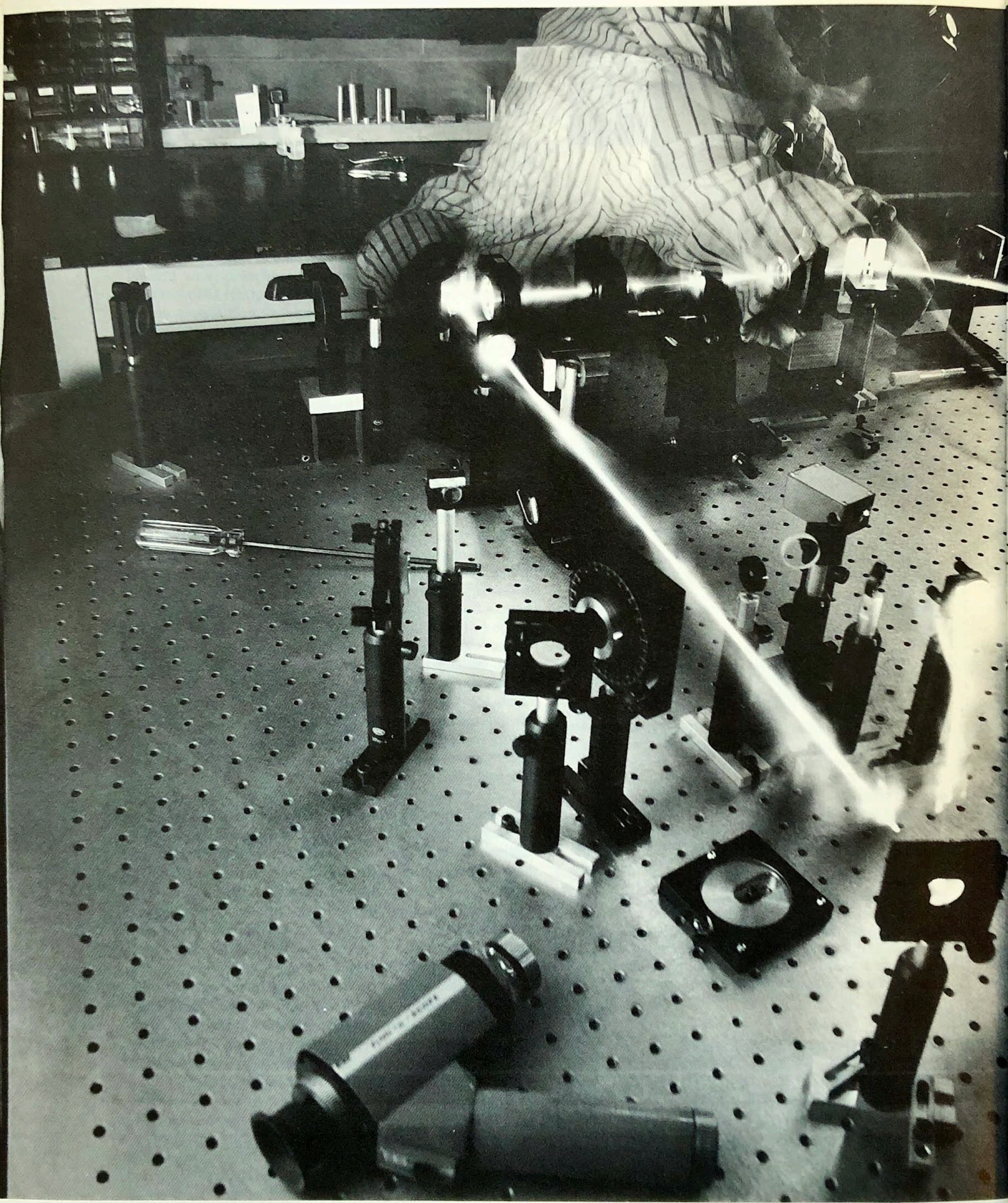
In the meantime, he continues his work with squeezed light. He skipped the November meeting of the Optical Society but later that month presented a paper at the conference on Quantum Aspects of Optical Communications in Paris, France. In January he will speak at a NATO conference on quantum optics in Cortina, Italy.

His latest paper deals with ideas that will no doubt constitute his fourth classical paper in the field. Working as always from basic principles, Yuen says he has developed a way to duplicate laser light while preserving some of its squeezed properties. The duplication process can be used for detection, by converting the light, or to amplify laser light, perhaps for fiber optics communications.

"This is just further development of squeezing," Yuen says. "It should carry quantum optics to another level."

But once again Yuen is ahead of his time. The NSF recently turned down a joint proposal with Kumar. And Kumar, who has succeeded in observing a 75 percent reduction in quantum noise and is considered a leader in the field, says no one has any good way at this point to carry out Yuen's latest idea in an actual experiment. But Kumar knows that time will come.

Chris Chandler is technical sciences editor in the Department of University Relations at Northwestern University.



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