Is Modern Physics for Real?

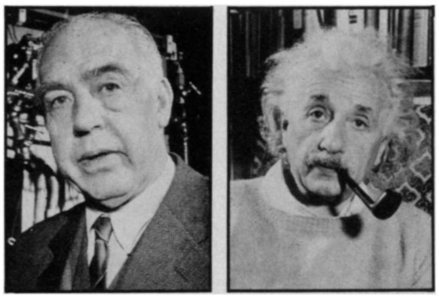
There is an old conundrum that schoolchildren sometimes pose to each other: If a tree falls in the forest, does it produce a sound if there is no ear to hear? The answer depends on your definition of sound. If sound is a wave in the air, then certainly there is sound when the tree falls. If sound is the perception of that wave, then there is no sound without an ear. But the acoustician's definition of sound is a wave in the air or whatever medium; science even speaks of sound that is inherently inaudible. From a scientific point of view the conundrum is entirely nugatory.

If one asks a somewhat familiar question of quantum mechanics, the result is less tautologous: If a photon is emitted by a glow in the universe 10 billion years ago, does it really exist, if in the year of grace nineteen hundred and seventy-six there is no eye to see it? The answer could well be, no, it does not exist.

That's absurd, shouts the mind brought up on the mechanistic philosophy of classical science. A thing has an objective reality of its own. The basis of science is objectivity. No observers or 10 observers, the photon is real, and the 10 observers should all see the same thing if they do it right. After all as Marie Curie said, "Physics concerns itself with facts not with people."

In the quantum domain, maybe not. John Wheeler of Princeton University, who may forgive us for calling him one of the elder statesmen of modern physics, reminds us that quantum physics, unlike other sciences, puts the observer into the picture. That peculiarity has caused seventy years of debate on the nature of reality and the meaning of observation. The end of the argument is not yet, and its pursuit is leading physicists and philosophers of physics into some rather esoteric ground. Some of the current speculation may prove crazy, but some of it may prove transcendentally sane.

Werner Heisenberg's famous uncertainty principle, which is one of the bases of quantum physics, illustrates one way the observer comes into the picture. Basically it says that you can't observe a reality without changing that reality. For example, if you want to know the position and momentum of an electron, classical physics says you may measure both with any desired precision. But in quantum physics, when you try, you find that is not so. To see where an electron is, you bounce a photon off it. You can determine its position by observing the reflected photon, but the act of reflection, the collision, has altered the electron's momentum by an unknown amount, so you are quite uncertain of the electron's momentum. Attempts to measure the momentum precisely lead to a complementary uncertainty in the position. The more precise you make the position, the bigger becomes the uncertainty of momentum and vice versa. You cannot measure position and momentum (with arbitrary precision) in the same act. It leads Wheeler to philosophize that: "Momentum or position only acquires a useful meaning on being observed." The potential exactness of both according to classical ideas loses its meaning.



Niels Bohr and Albert Einstein engaged in a long debate over the logical consistency of quantum physics and its relation to the usual definitions of reality. The argument was one of the great events in the history of natural philosophy.

BY DIETRICK E. THOMSEN

An equally important formulation of Heisenberg's uncertainty principle posits exactly the same reciprocal uncertainty between the time a particle is emitted by something and the amount of energy it carries away. This aspect of the principle is important in modern particle physics because it permits all manner of violations of classical laws, violations that allow the business of particle physics to get done.

Quantum physics thus has at its basis uncertainty, duality and paradox. Another most important example, which is connected to the uncertainty principle is the wave-particle duality. Every particle also has a related wave that gives us information about the particle and determines important aspects of its behavior, such as the size of the orbits of electrons around the nucleus of an atom.

The people who formulated quantum physics were mostly quite dismayed by all this. They had been brought up as good classical physicists, and most of them moved away from classical principles of unity, simplicity and causality *à contre coeur* and only under the empirical compulsion of the phenomena. Erwin Schrödinger, who invented one form of the mechanics of quantum entities, once remarked that he wished he had never had anything to do with the subject. Albert Einstein's attitude is summed up in two famous dicta, by which he rejected both the paradoxical dualities of quantum physics and the chancy indeterminism that they lead to. The first runs: "God is subtle, but He is not malicious." The second: "God does not throw dice."

Of all the pioneers of modern physics Niels Bohr seemed the most at home with quantum ideas, and if not necessarily happy, at least resigned. He used them quite enthusiastically to solve outstanding problems of atomic and molecular physics, and he tried to formulate philosophical principles that would give quantum mechanics ideological respectability.

The difference in attitude caused a decades-long debate between Einstein and Bohr, that Wheeler says, is one of the truly great things of history. It had two phases, which took place before and after Einstein moved to America. While he lived in Europe, Einstein was concerned to prove the logical inconsistency of quantum physics. Later he shifted to an attempt to show that quantum physics was incompatible with any reasonable picture of reality.

Einstein's most celebrated confrontation with Bohr came at the 1930 Solvay conference and concerns the famous thought experiment of the Einstein box, by which Einstein tried to make hash of the time-energy formulation of the uncertainty principle. Consider a box that emits a quantum of energy. The hole through which the emission takes place is fitted with a shutter that is connected to a clock. As it chops off the quantum, the shutter makes the clock record the exact time. If you weigh the box before and after the emission, you can tell exactly how much energy it lost (mass and energy being

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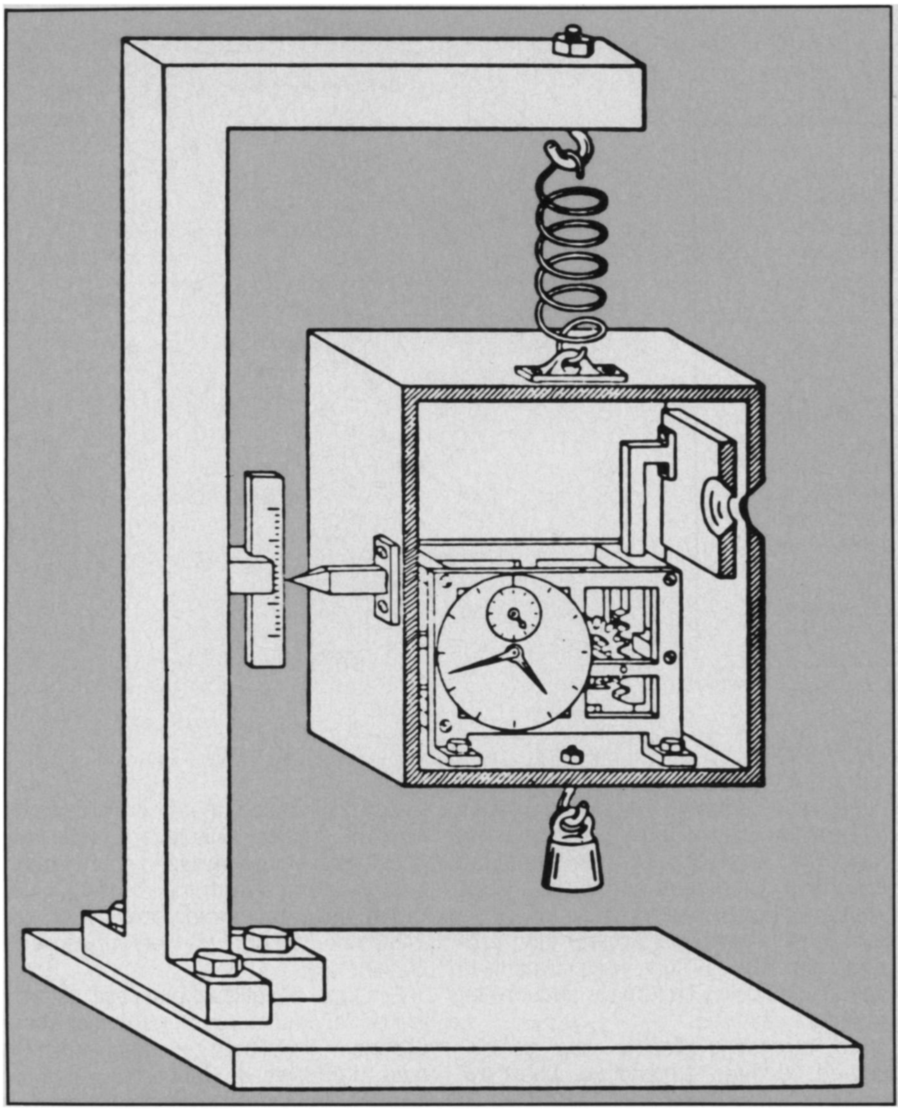


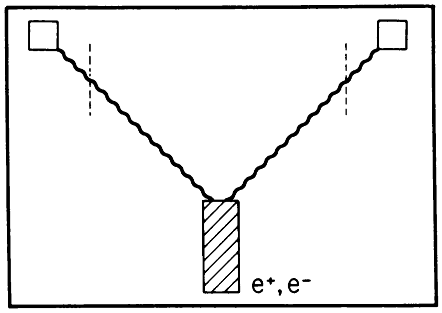
Illustrations/Joseph Henry Laboratories

Bohr used Einstein's own theory of general relativity to show that the clock rate had to be uncertain in Einstein's quantum-emitting box proposal.

equivalent), and so you have violated the uncertainty principle.

Bohr thought about this all night, and came back in the morning and hoisted Einstein with his own general relativistic petard. They had agreed the day before that to determine the energy difference exactly, the whole system including the clock, had to be weighed. Einstein had agreed to put the clock inside the box. Bohr then pointed out that Einstein's general relativity says that a clock's rate depends on the strength of the gravitational field in which it finds itself. If the box is suspended from a spring so as to monitor its weight, then it will move up as it loses the emitted quantum. This changes the clock's position in the gravitational field and introduces an uncertain change in its rate, leading to an uncertainty in the time measurement, and so the uncertainty principle is preserved.

Einstein went away to think about things. After his emigration to the United States, he came back, not with another attack on the logical consistency of quantum physics, but with a blast at its compatibility with any sensible definition of reality. This is called the Einstein-Rosen-Podolsky paradox, including the names of two other men who also worked on it.



E-R-P paradox: Photons (wiggly lines) are emitted in electron-positron annihilation. Centuries later (time moves in the vertical direction) they have their polarization determined (dashed lines) and are detected by Kerr cell (open boxes).

The paradox goes like this: Suppose there is an atom of positronium, that is, an electron and a positron revolving around each other. This system is unstable and likely to annihilate itself. When it does, it emits two photons or quanta of light. The two photons must, by the dynamics of their production, have opposite polarizations. The two photons fly off in different directions.

Suppose further that the two photons have been flying for years so that they are by now several light years apart. An experimenter is located in a proper position to catch one of them, another is located to catch the other. The experimenters put polarizers in the paths of the photons and detectors to record them.

The idea is that one experimenter sets his polarizer so that it will pass only a photon of a certain polarity. If the photon passes and is detected, the experimenter immediately knows how his opposite number 10 or 15 light-years away must have set his polarizer to pass his photon.

What we have here is either a paradox of communication or one of causality. Either the information on the setting of the polarizers is transmitted instantaneously from one experimenter to the other, in defiance of all known physical laws, which would otherwise require transmission of information by a carrier that can move no faster than light, or an action in the here and now (setting the polarizer) can control an event in the remote past (the dynamics of the positron annilation that produced a particular polarization).

Contemplating the communications aspect has led some physicists to muse on the possibility of real instantaneous communication. This can go on to extrasensory perception and other suggestions that sound decidedly unscientific.

In fact, Bohr's response was to deny the possibility of any instantaneous communication by what Wheeler calls "a final renunciation of causality." There is no reality to photon polarization; polarization has no meaning until we are there and observe it. We ourselves, 10 billion years down the line, can determine the polarity of a gamma ray from the big bang. In a way, Bohr won the debate by sacrificing traditional physics.

Thus, quantum mechanics makes the observer a participator. Not only in Heisenberg's sense that the observer disturbs what he measures, but in the more profound sense that his choices of what to measure will determine what he finds. Reality has no objective existence apart from the act of observation. "In some strange sense," says Wheeler, "this is a participatory universe. What we have been accustomed to call 'physical reality' turns out to be largely a papier maché construction of our imagination plastered in between the solid iron pillars of our observations. These observations constitute the only reality."

Wheeler concludes: "Until we see why the universe is built this way, we have not understood the first thing about it. . . . We can well believe that we will first understand how simple the universe is when we recognize how strange it is." ☐