Louis de Broglie, the father of wave mechanics

Laurent Rosenfeld, in a eulogy for one of the great physicists of the century, looks at quantum mechanics and the Copenhagen School's interpretation of probabilistic waves.

With the death of Prince Louis de Broglie on March 19 at age 94, modern theoretical physics lost one its most eminent founders. Louis de Broglie was, indeed, with Paul Dirac, the last survivor of that small group of individuals who imposed on fundamental physics an extraordinary revolution. Indeed, the full consequences of their work have yet to be realized.

The giants of this formidable physical revolution included such names as Planck, Lorentz, J.J. Thomson, Curie, Einstein, Millikan, Schroedinger, Rutherford, Heisenberg, Compton, Born, Bohr, Pauli, Langevin, Perrin, Chadwick, etc. But even among this lofty circle of Nobel Prize winners, de Broglie held a position that made him the peer of the greatest.

It is only right that de Broglie is considered the father of wave mechanics, a physical theory which is complementary to quantum mechanics—but in contradiction with its most common interpretation. While de Broglie's theory has been relegated to the background somewhat, through the brutal offensive of a scientific clique usually christened the "Copenhagen School" of Niels Bohr, Wolfgang Pauli, and Werner Heisenberg, we are convinced that we have not heard the last of it.

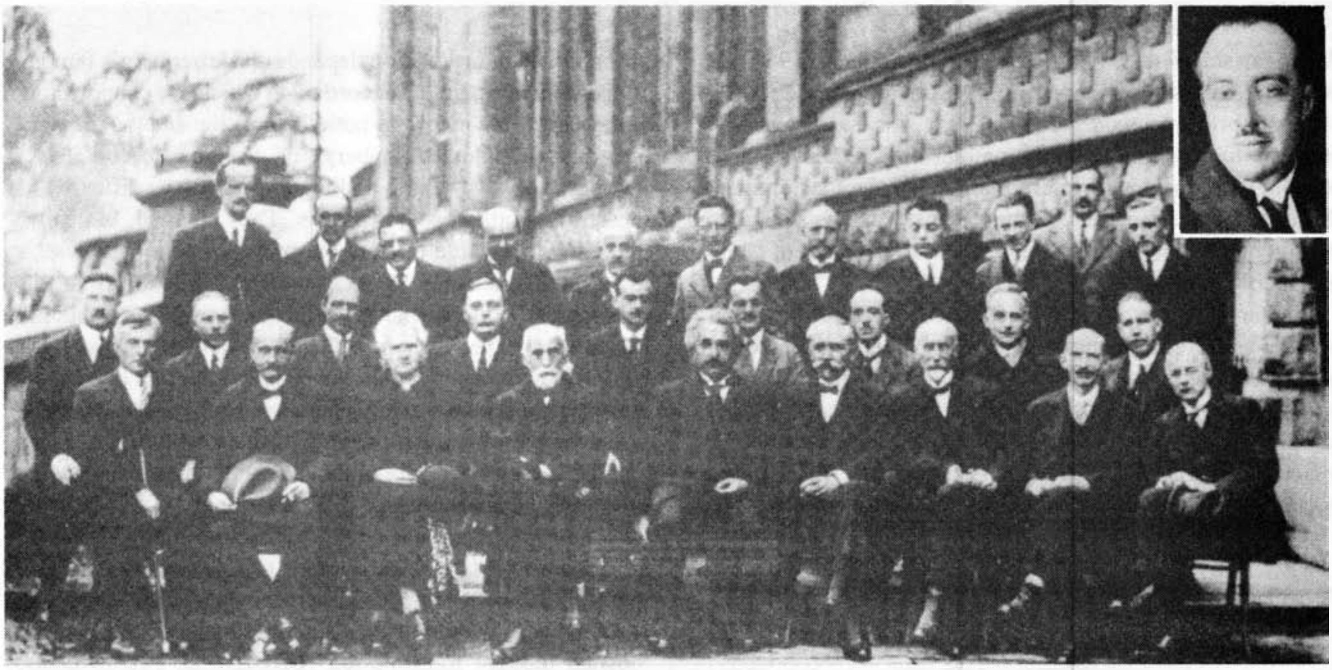
Physics divided

Born on Aug. 15, 1892, into a French aristocratic family, de Broglie did not originally intend to work on fundamental physics. He was more interested in the history of the sciences. During the war, he worked in the wireless station at the Eiffel Tower, which acquainted him with electromagnetics. But his brother, Maurice de Broglie, interested him in working on fundamental physics soon after World War I.

At that time, physics was again agitated by the old controversy which had originally placed Newton in opposition to Huygens in the 17th century: the nature of light. Is light a particle beam emission, or the propagation of a wave? At the beginning of the 19th century, Thomas Young, François Arago, and especially Augustin Fresnel had settled the question in favor of a wave theory, to which Maxwell gave an electrodynamic and thermodynamic formalization which was to raise some complex paradoxes. The most serious of these difficulties was known under the name of the "ultraviolet catastrophe," which de Broglie described in the following terms:

"Physics was somehow divided into two parts: on the one hand, the physics of matter, founded on the idea of corpuscles and atoms which were believed to obey the classical laws of Newton's mechanics, and on the other hand, the physics of radiation, starting from the idea of wave propagation in a hypothetical continuous medium: light and electromagnetic ether. But these two physics could not remain foreign to each other: They had to be welded together by designing a theory of energy exchanges between matter and radiation, and that is where the trouble erupted. By trying to connect the two physics, one reached untrue or even intolerable conclusions on the question of equilibrium between matter and radiation in a thermally isolated, closed space: Matter, one would end up saying, would release all its energy to radiation, and therefore eventually tend to a temperature of 0° K. This absurd conclusion had to be avoided at all costs!"

Solving this paradox brought Max Planck and Albert Einstein to formulate a quantum theory, according to which, interactions between light and matter would proceed only by



At the Oct. 23-29, 1927 Solvay Conference, scientific thugs like Neils Bohr imposed their anti-causal interpretation of quantum physics over the objections of, among others, Louis de Broglie (middle row, third from left, and inset).

discrete jumps of energy—quanta. The energy of each quantum was equal to the frequency of the radiation multiplied by the famous Planck Constant.

But this idea suggested for light a granulary or corpuscular structure, which was confirmed by the discovery of the photoelectric effect and its theoretical analysis by Einstein: If a metal piece was irradiated by x-rays (which had just been discovered by Roentgen), it would emit electrons whose energy did not depend on the intensity, but only on the frequency of the incident radiation; intensity had an effect only on the number of electrons thus released. In other words, as Einstein proved, everything works as if light was made up of grains, soon to be called photons, which could one-by-one extract an electron from matter; if the photons had an unsufficient energy (corresponding to too low a frequency), no electron would be emitted, whatever the intensity of the radiation.

Was the Newtonian corpuscular-emission theory going to triumph? It was not all that simple, since Fresnel's arguments in favor of the wave theory remained pretty strong. Specifically, diffraction and light interferences could not be explained in the framework of a corpuscular theory. Furthermore, as de Broglie stressed at the address he gave in Stockholm upon receiving his Nobel Prize:

"When I started to work on these difficulties, two things struck me. On the one side, the quantum theory of light cannot be considered satisfactory, since it defines the energy of a corpuscle through the relation $W = h\nu$, where the frequency ν is present. Yet, a purely corpuscular theory contains no element which could define a frequency."

One thus had to accept a "wave-particle duality" of light, depending on the case at hand. It is easily understood that this situation was not very satisfactory.

De Broglie's solution

Very schematically, de Broglie solved this duality problem by conjugating these two features of light; he showed that every particle, including for example an electron beam, was associated with a wave. In other words, he gave a wave nature to what was firmly believed until then to be pure particles, and his calculations predicted the wave length to be equal to the Planck constant h divided by the momentum P of the particle. In April 1925, Davisson and Germer, of the Bell Telephone Company, noticed that, indeed, electrons bouncing off a nickel plate underwent the interferences predicted by de Broglie's theory, thus proving their wave nature; they also confirmed de Broglie's calculations. De Broglie's interpretation consisted of associating to each particle (be it a photon or a mass-particle such as an electron) a "pilot wave," guiding the movement of the particle.

The Copenhagen school replaced this view by a probabilistic theory, according to which the wave represents only the probability of a particle being in a specific place at a given time. Using quite literally a form of intellectual terrorism, especially during the famous Solvay Conference in Brussels in 1927, the Copenhagen School defeated its opponents. Even Albert Einstein, who rejected the probabilistic interpretation throughout his life, did not then dare to oppose Niels Bohr, Max Born, Wolfgang Pauli, and Werner Heisenberg.

Demoralized, de Broglie surrendered his views and accepted this anti-scientific theory, and even taught it for years. However, he later returned to his original view when the

American scientist, David Bohm, demonstrated in 1952 that Bohr's arguments (an "impossibility proof") against de Broglie's interpretation were wrong. Today, the two interpretations are in principle possible, neither one of them is ruled out, but the Copenhagen interpretation is by far the dominant theory, to a large extent because most scientists tend to wrongly credit this interpretation with the successes of quantum theory equations.

In our view, we are convinced that de Broglie's interpretation was closer to reality than Bohr's. Indeed, by rejecting all *causality* at the microscopic level, the probabilistic interpretation raises a lot of fundamental questions. "God does not play dice," Einstein once said against this probabilistic vision. On this account, Einstein, Podolski, and Rosen raised an interesting problem, known as the EPR paradox. The probabilistic interpretation depends on Heisenberg's famous "uncertainty principle," according to which one cannot know at the same time precisely both the position and the momentum of a particle. Heisenberg and Bohr made out of it a fundamental law, having nothing to do with the difficulty of measuring both those parameters. They claimed, basically, that it is impossible to state the presence of a particle at a given point, but only to assert a certain probability to this occurrence. Einstein and his colleagues proposed a thought (*Gedanken*) experiment in which, for example, the materialization of a photon provokes the emission of a pair of particle/anti-particles ejected in opposite directions. It would then be possible to measure the position of one of the two particles and the velocity and spin of the other, and then calculate the other parameters for each.

The experiment was conducted recently, but did not go so far as to measure clearly these parameters. But the fact that it could not be done does not mean that it cannot be done. It seems very dangerous for the mind to accept the kind of "instant thought transmission" between the two particles, according to which one particle would somehow "know" that the other is being measured. Maybe the acceptance of such weird visions is the cause of the craziness surrounding "paranormal phenomena" and the various "gnoses" which have come to dominate some circles of physical research. One thing is sure: Present physical theories (the quark theory, for example) have lost their ability to *forecast* new physical effects—whereas that ability should be the criterion for validity and fruitfulness of a scientific theory.

Interferences

Another interesting question touches upon the physical significance assigned to interferences between "probability waves." For example, if we think of interferences in a Young device, where light or particle rays are passing through two thin slits and interfering behind on a screen, the probability of having particles reach a certain place through the two slits may be lower than the probability of having these particles reach the same place through only one of the two slits! This does not make much physical sense. Clearly, de Broglie's idea of "pilot wave," despite possible unclarities, makes much more sense. We don't know whether de Broglie's interpretation is really the correct one, but it seems undoubtedly closer to physical reality. Be that as it may, de Broglie will remain the man who imposed the idea of a wave being associated with particles, and that alone is sufficient to have us venerate his memory.

The author wishes to conclude on a personal remark. When I was in my early 20s, I had the opportunity to read several of de Broglie's works and books. I found in them a great source of inspiration and it was with a very deep emotion that I had a brief exchange of views with this exceptional man. Let us weep his death, but may his mind continue to inspire and guide young generations!