Particle Billiards, Captured on Film

One of the strongest arguments for the quantum nature of light was provided in the mid-1920s by **Walther Bothe**, who was appointed Director of the Institute for Physics at the **Kaiser Wilhelm/ Max Planck Institute for Medical Research in Heidelberg** in 1933. Together with Hans Geiger, he developed a method to accurately record the timing of particle processes. This coincidence measurement is still a universal method in physics.

TEXT **ELKE MAIER**

Waves or particles – or both? Many scientists had been racking their brains over the nature of light when two physicists set about researching the properties of scattered radiation in 1924. Walther Bothe and Hans Geiger confirmed the quantum theory using a sophisticated experiment – and at the same time discovered a universal method of researching particle processes. Bothe entered the history books in 1954 when he won the Nobel Prize for developing this coincidence method. Geiger had already died by then, but his name lives on in the instruments used to measure radioactivity.

Walther Bothe was born on January 8, 1891 in Oranienburg, a town north of Berlin. A talent for creating accurate measuring instruments clearly ran in the family – his father was a master watchmaker. The young Bothe gravitated toward science, but only after abandoning a banking apprenticeship. After studying mathematics, physics and chemistry at the University of Berlin, he applied to study for a doctorate with Max Planck, who was known to be extremely discerning in his choice of students.

But fortune smiled on Bothe. “What topic did you have in mind?” Planck wanted to know. Bothe mentioned a theoretical topic relating to optics. “Yes, you could try that,” was the response. Three months later, the diligent doctoral student presented his results. “But that’s not enough,” said Planck. Another three months passed: “Good, now you can write it up.”

They gave physics a universal method of researching particle processes: Walther Bothe (left) and Hans Geiger.

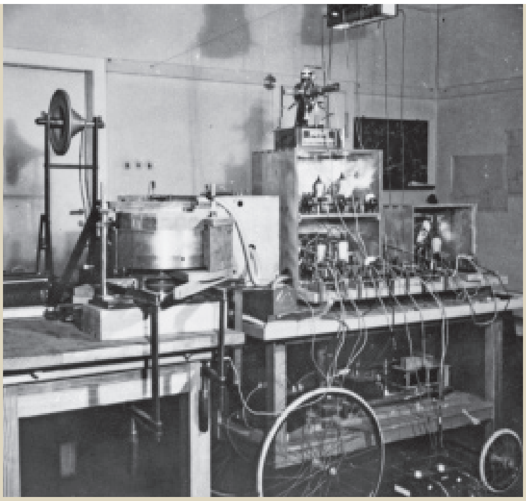
Photo: Archives of the Max Planck Society

Following this training in independent scientific work, Walther Bothe joined the new laboratory for radioactivity at the Physikalisch-Technischen Reichsanstalt (Physical and Technical Institute) in Charlottenburg. Heading up the lab was Hans Geiger, who had worked with Ernest Rutherford in England. Geiger had thus learned his trade with one of the most eminent authorities on radioactivity. Walther Bothe considered his boss, who was roughly eight years his senior, to be his scientific mentor. Together with Geiger, he celebrated his first major research success in 1925.

The starting point for this success was the experiments conducted by American physicist Arthur Holly Compton, who had bombarded crystals with hard X-rays. In doing so, he discovered that when an X-ray collides with an electron in the atomic shell, it transmits part of its energy to this electron before continuing to travel as energy-depleted scattered light. During the collision, a recoil electron is emitted that leaves the atomic shell at a precisely predetermined angle – similar to a billiard ball that bounces off the cushion and on the rebound takes a precisely determined direction.

Opinions differed about this Compton Effect. Albert Einstein and Arthur Holly Compton believed that the number of light quanta should match the number of recoil electrons exactly. Consequently, energy and momentum would have to be retained in the system. Niels Bohr and his colleagues Hendrik A. Kramers and John Slater saw it differently. In February 1924, they submitted to the physics journal ZEITSCHRIFT FÜR PHYSIK a theory that stated that the number of scattered light quanta and recoil electrons should be the same only in the matter, but not in the individual atomic processes.

Bohr and his researchers wanted to use this hypothesis to find a way out of the wave-particle dilemma. To this end, they questioned the general validity of the law of conservation of energy, shaking the very foundations of physics. Wolfgang Pauli, an avowed opponent of the theory, referred to the detailed hypotheses as the “Copenhagen putsch.”



Walther Bothe investigated the quantum nature of light using sophisticated experiments. The photo shows a measuring instrument in his laboratory in 1939.

Bothe and Geiger also became involved in the scientific dispute. Shortly after Bohr and his colleagues published their theory, the German scientists announced, in the same journal, an experiment designed to restore order. To do this, they devised a sophisticated measuring instrument consisting of two opposing needle counters. An X-ray was passed through the gap between these counters. While one of the counters responded only to the light quanta, the other registered only the recoil electrons. The deflections of the "light counter" and the "electron counter" were recorded on silver bromide film that moved past the counters at high speed. Fine strips on the film allowed the scientists to precisely record the timing of the particles as they collided.

According to the authors, if a quantum of light and a recoil electron collided simultaneously and their joint impact could be measured as a coincidence, then the particle nature of light would be confirmed and the law of conservation of energy proven also at the atomic level. If, in contrast, there were a delay in the response by the two counters, that would argue against the particle nature of light and the strict validity of the law of conservation of energy – thus giving credence to the agitators in Denmark.

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» Bothe was a strict boss and often a vocal critic – but his staff knew that he was always willing to stand up for them. In his spare time, he was an excellent piano player and particularly enjoyed playing Bach. That brought him into contact with prominent musicians in Heidelberg into the 1950s. Many old Heidelberg residents still remember his hospitality.«

The experiment proved to be laborious and time consuming. In order to obtain statistically solid results, the two researchers had to develop, dry and evaluate more than three kilometers of the just 1.5-centimeter-wide film – in addition to all their other duties at the institute. It was almost a year before the results were finally available. Bothe and Geiger showed that, with an accuracy of one ten-thousandth of a second, the "light counter" and the "electron counter" responded simultaneously.

The plausibility of the Copenhagen theory was thus refuted. The experimenters meanwhile responded modestly: "One must therefore reasonably well assume that the concept of the light quantum possesses a higher degree of reality than admitted in this theory," was their conclusion regarding their results. In fact, Walther Bothe and Hans Geiger had provided one of the strongest arguments for Einstein's light quanta.

Compton considered the experiment to be "brilliantly performed." And physicist Max von Laue later declared: "Physics was saved from being led astray." Wolfgang Pauli could not help mocking the team. He recommended that the Copenhagen-based institute always "fly its flag at half mast on the anniversary of the publication of the work of Bohr, Kramers and Slater."

Later in 1925, Hans Geiger took up a position in Kiel in northern Germany, where he worked with his Ph.D. student Walther Müller to develop the Geiger-Müller tube. This "Geiger counter" brought him worldwide fame. Walther Bothe succeeded him in the Physikalisch-Technische Reichsanstalt, and in the years that followed, published even more experiments in which he applied the coincidence method. Together with physicist Werner Kohlhörster, he studied cosmic radiation, which the Austrian physicist Victor Franz Hess had discovered on August 7, 1912 during a balloon trip. The two researchers took to the roof of the institute in Berlin and also embarked on a voyage to the edge of the pack ice in Spitsbergen to obtain their measurements.

They were able to prove that the mysterious radiation from the universe was not, as had been previously assumed, short-wave gamma radiation, but instead a stream of charged particles. Bothe and Kohlhörster measured coincidences – even if they placed a thick sheet of lead between the counters. They concluded correctly that the radiation must have a huge energy content of more than 1,000 million electron volts – a thousand times more energy than was known in nuclear physics.

Bothe gave up his tenured professorship at Heidelberg University and, in 1934, took over as head of the physics sub-institute at the Kaiser Wilhelm Institute for Medical Research. There, he worked mainly on problems relating to the controlled nuclear fission chain reaction and on setting up the first German cyclotron in Heidelberg – a project that was classified as essential to the war effort. The Nazi era was an extremely disruptive period for the institute. The hopes of the German Army Ordnance Office that Bothe's research could be essential to the war effort were dashed by the collapse of the Nazi regime.

In 1954, Walther Bothe – then Director of the Institute for Physics at Heidelberg's Max Planck Institute for Medical Research – received the Nobel Prize for Physics and specifically "for the coincidence method and his discoveries made therewith." Had Hans Geiger still been alive at that time, the honor would no doubt have been bestowed on the two of them. Walther Bothe died on February 8, 1957.

Coincidence measurement is still indispensable today in researching the world of atoms and elementary particles. By exactly recording the timing of particle collisions, scientists can determine their ranges, speeds and even trajectories. Now they are making inroads in ranges of less than one billionth of a second. Bothe would surely be impressed by such temporal precision – as would his father, the watchmaker.

Photo: Archives of the Max Planck Society