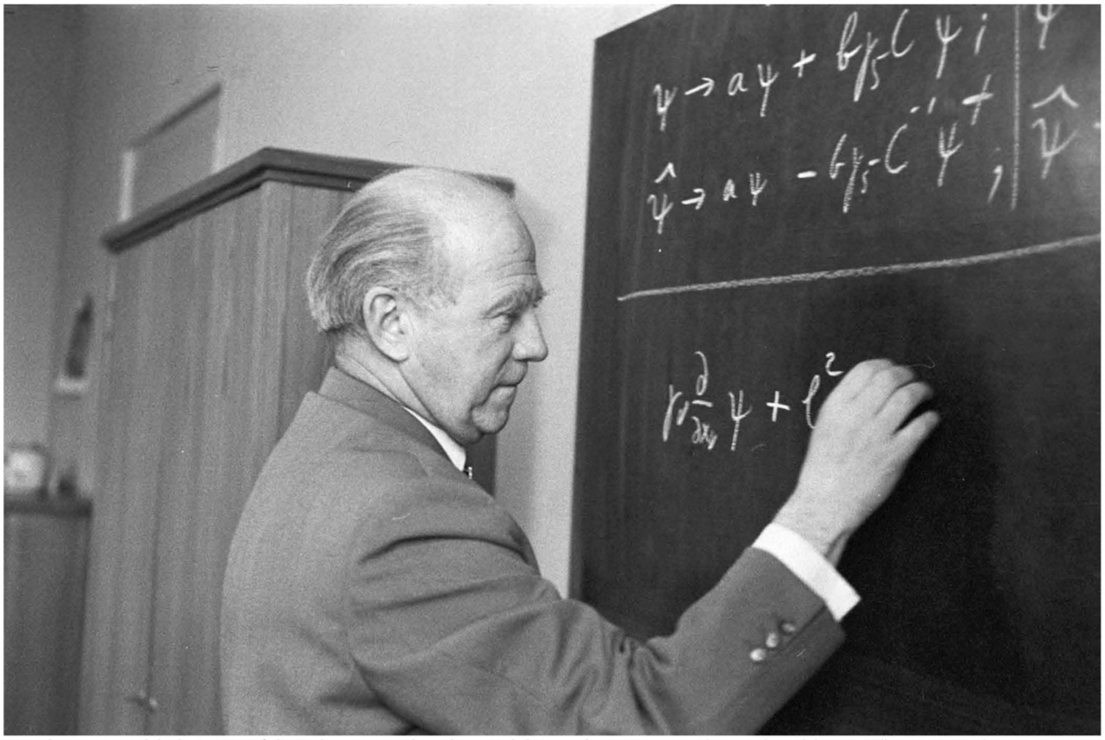

**Heisenberg expressed the limitations of classical concepts with mathematical clarity and precision** Photograph © Philippe Le Tellier / Paris Match via Getty Images

had been hailed as an enormous achievement and was being studied by physicists throughout Europe.

In the discussion following one of these lectures, Heisenberg disagreed with Bohr about a particular technical point. Bohr was so impressed by the clear arguments of this young student that he invited him to come for a walk, so that they could carry on their discussion. This walk, which lasted for several hours, was the first meeting of two outstanding minds whose further interaction was to become a major force in the development of atomic physics.

Bohr, 16 years older than Heisenberg, was a man with supreme intuition and a deep appreciation for the mysteries of the world; a man influenced by the religious philosophy of Kierkegaard and the mystical writings of William James. Heisenberg, on the other hand, had a clear, analytic and mathematical mind, and was rooted philosophically in Greek thought, with which he had been familiar since his early youth. The dynamic, and often dramatic, interplay of these two complementary minds was a unique process in the history of modern science and led to one of its greatest triumphs.

At that time, the investigations of atomic physicists were plagued by a number of paradoxes and apparent contradictions between the results of different experiments. Many of these paradoxes were connected with the dual nature of subatomic matter, which appeared sometimes as particles, sometimes as waves: a most puzzling behaviour that was also exhibited by light or, more generally, by electromagnetic radiation.

Light, for example, was found to be emitted and absorbed in the form of quanta, but when these particles of light (now known as photons) travelled through space, they appeared as vibrating electric and magnetic fields that showed all the characteristic behaviour of waves. Electrons had always been considered to be particles, and yet when a beam of these particles was sent through a small slit, it was bent just like a beam of light. In other words, electrons, too, behaved like waves. The strange thing was that, the more physicists tried to clarify the situation, the sharper the paradoxes became.

Here, Heisenberg made his first crucial contribution. He saw that the paradoxes in atomic physics appeared whenever one tried to describe atomic phenomena in classical terms, and he was bold enough to throw away the classical conceptual framework. In 1925, he published a paper in which he abandoned the classical description of electron motion in terms of the positions and velocities of the electrons. He replaced it with a much more abstract framework, in which physical quantities were represented by sets of numbers known as matrices. The whole formulation is now known as Heisenberg's matrix mechanics. It was the first logically consistent formulation of quantum theory.

One year later, it was supplemented by a different formulation, worked out by Erwin Schrödinger and known as wave mechanics. Both formulations are logically consistent and are mathematically equivalent; the same atomic phenomena can be described in two different mathematical languages.

At the end of 1926, then, physicists had a complete and