

## Werner Heisenberg (1901 - 1976) His Life and Science

Werner Heisenberg was one of the most important physicists of the twentieth century. He was the first to consistently formulate quantum mechanics in 1925. His version used matrices to represent physical observables and is thus known as "Matrix Mechanics". A little later, quantum mechanics was discovered in another formulation, now known as Wave Mechanics, by Erwin Schrödinger. Soon, the equivalence between the two formulations, despite their being seemingly very different from each other, was shown by Eckart and by Schrödinger.

Werner Heisenberg was born in Würzburg on December 5, 1901 to August Heisenberg, a Professor of Greek Philology. His mother Annie née Wecklein was the daughter of a headmaster in Maximilian Gymnasium at Munich, where he had his early education. He became the leader of a group of boys, associated with a "German Youth Movement" from the military unit of his school. This movement was somewhat right wing and had anti-modernist romantic leanings. His personality was moulded by this participation.

Heisenberg joined the University of Munich in the fall of 1920 and obtained his doctorate in 1923 working with Arnold Sommerfeld. He worked mainly on the problems of old quantum theory. During 1922 - 1923 when Sommerfeld was away at the University of Wisconsin, he went to study with Max Born at Göttingen. In view of the fact that Heisenberg's work on atomic physics generally involved a fair amount of daring and speculative elements, Sommerfeld told him "It is not good always to walk in the mud, you should really do decent mathematical work in theoretical physics".

He therefore suggested "the stability of laminar flow" in hydrodynamics as his dissertation topic. Heisenberg received his doctorate with an overall grade of only III which was just sufficient to get the degree. This seems to have been a compromise between grade I, i.e. excellent, which Sommerfeld gave him and grade V i.e. fail, which Wien gave him. Heisenberg had not been doing too well in Wien's laboratory course and was also not able to answer Wien's various questions at oral exams, including one about the resolving power of a microscope. Heisenberg clearly learned answers to these topics as the gamma-ray microscope plays a crucial role in his famous paper on "Uncertainty Principle" later in 1927.

After his doctorate, he moved to Göttingen with Max Born who was still willing to have him as an assistant despite the poor showing with Wien. He stayed there till the spring of 1926. During this period, he however visited the group of Niels Bohr at Copenhagen during the academic year 1924-25. At Copenhagen he worked on dispersion theory with Kramers. As Heisenberg says "From Sommerfeld I learned optimism, from the Göttingen people mathematics and from Bohr physics".

The successful work in the old quantum theory involved tight rope walking. One was forced to use classical concepts, which one knew were not valid in the atomic domain and then marry them somehow to quantisation conditions. Heisenberg keenly felt during his work on dispersion theory "that finally there must be some kind of quantum mechanics which has to replace classical mechanics". He returned to Göttingen in April 1925 as a privatdozent.

At Göttingen, inspired by what he thought was Einstein's view that only physical observables should appear in a theory, he focused his interest on amplitudes and frequencies which occur when a Fourier decomposition of an orbit, i.e. electron position  $X(t)$ , is done. He replaced the Fourier amplitude  $X_m(n)$  of an orbit position, referring to  $n$ th orbit with  $m$ -th harmonic of frequency  $\omega(n)$ , by new quantities

$$X_m(n) \rightarrow X(n, n-m) = \langle n | X | n-m \rangle,$$

$$m\omega(n) \rightarrow \omega(n, n-m) = \varepsilon(n) - \varepsilon(n-m)$$

referring to two states  $n$  and  $(n-m)$  between which the transition takes place. The second of these is just Bohr's frequency condition. This was his reinterpretation of classical quantities.

In June 1925, he took a vacation at the desolate rocky island of Helgoland in the North Sea to get rid of persistent hay fever. At Helgoland, the various pieces of the puzzle fell into place. He found his reinterpreted quantities, which obeyed what we would now call matrix multiplication rules, needed one more ingredient to give a complete scheme. It was to replace Bohr's quantisation conditions of the old theory by the analog of the sum rule of Thomas and Kuhn for these quantities. In modern terms, he discovered the commutation rules between momentum  $P$  and position  $X$ . More precisely he had discovered the diagonal matrix elements of that commutation rule. The discovery of matrix mechanics ushered in the quantum revolution in human thought.

Born immediately recognized that "Heisenberg's symbolic manipulation was nothing but matrix calculus". Soon Born and Heisenberg, together with Jordan, gave a complete formulation of matrix mechanics by October 1925. Heisenberg

returned to Bohr's institute at Copenhagen as his assistant in May 1926. The nerve wracking discussions with Bohr soon began about the proper interpretation of quantum mechanics. Heisenberg formulated in February 1927 his celebrated Uncertainty Principle, according to which "the more precisely the position is determined, the less precisely the momentum is known in this instant and vice versa". He was greatly inspired in this by a discussion he had with Einstein in Berlin in 1926 where Einstein emphasized to him "It is the theory which decides what can be observed". Bohr, who was away on a skiing vacation at this time had formulated his "Complementarity Principle". All these discussions eventually resulted in the so called "Copenhagen Interpretation of Quantum mechanics", which remained for a long time as the "Standard interpretation".

Heisenberg applied the new quantum theory to give an explanation of the anomalous Zeeman effect, and of the splitting between Ortho and Para Helium spectra. Heisenberg was appointed Professor of Theoretical Physics at the University of Leipzig in October 1927. At the age of 25, he was the youngest Professor in Germany. In Leipzig he developed a strong research group. His work on Ferromagnetism in 1928, wherein he proposed that electrostatic interaction between electrons together with Pauli principle is responsible for this phenomenon, was the first important result to come out. He also proposed in 1932 the present model of nuclei in which their constituents were protons and neutrons, soon after the discovery of neutrons by Chadwick. The foundational work of Pauli and Heisenberg on quantum electrodynamics also dates from this period. Heisenberg was awarded the Nobel Prize for the year 1932. He received it in December 1933.

In January 1933 Adolf Hitler came to power in Germany. The policy of purging Germany of Jews from its cultural life was set in motion. Jewish scientists were removed from their jobs and many of them migrated to other countries. Heisenberg decided to remain in Germany as he thought that by remaining there something of value in German culture could be saved. Planck also advised him to remain. He also had an attachment to a romantic idea of Germany from his "Youth movement" days. Even he was attacked as a "White Jew" by Nazis when he tried to oppose Stark and Lenard's campaign to declare quantum theory and relativity as "Jewish Physics" which should be rooted out. In April 1937, he married Elisabeth Schumacher who was a source of strength for him.

The Second World War broke out on September 1, 1939. Soon he was asked to join Germany's nuclear fission research project as part of its war effort. He divided his time working with a small nuclear reactor at Leipzig, which he headed, and visiting Berlin to advise a larger group there till 1942. After that, he shifted to Kaiser Wilhelm Institute for Physics at Berlin to direct the fission research. It is a highly controversial subject as to why he collaborated with Hitler's Germany to work on their Atomic Bomb Project. The Project

was a failure. Recently, his role during the Second World War has elicited a lot of public interest after the successful play 'Copenhagen' by Michael Frayn dealing with his visit to Niels Bohr in September 1941.

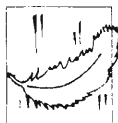
In 1943, Heisenberg proposed the S-matrix theory of high energy particle interactions, which was in great vogue in the 1960s and 1970s.

After the War, Heisenberg played a leading role in rebuilding German Science. He was made Director of Kaiser-Wilhelm Institute in July 1946. Later the institute's name was changed to Max-Planck Institute and it moved to Munich. He was involved in setting up CERN at Geneva. In 1953 he became President of the Alexander von Humboldt Foundation. He died of cancer on February 1, 1976 at Munich.

Werner Heisenberg was a colossus of twentieth century physics who left his mark on its science and polity.

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To be sure, rational thinking and careful measurement belong to the scientist's work, just as the hammer and chisel belong to the work of the sculptor. But in both cases they are merely the tools and not the content of the work.

– *Werner Heisenberg*