Werner Karl Heisenberg

Born: 5 Dec 1901 in Würzburg, Germany
Died: 1 Feb 1976 in Munich, Germany

Werner Heisenberg's father was August Heisenberg and his mother was Anna Wecklein. At the time that Werner was born his father was about to progress from being a school teacher of classical languages to being appointed as a Privatdozent at the University of Würzburg. Anna's father, Nikolaus Wecklein, was the headmaster of the Maximilians Gymnasium in Munich and it was while August Heisenberg was a trainee teacher at that school that he had met Anna. August and Anna were married in May 1899. Werner had an older brother Erwin, born in March 1900, who was therefore nearly two years older than the subject of this biography.

August Heisenberg was [3]:-

... a rather stiff, tightly controlled, authoritarian figure.

He was an Evangelical Lutheran and his wife Anna had converted from being a Roman Catholic to make sure there were no religious problems with their marriage. August and Anna, however, were only religious for the sake of convention. A Christian belief was expected of people of their status so for them it was a social necessity. In private, however, they expressed their lack of religious beliefs, and in particular they brought up their children to follow Christian ethics but showed total disbelief in the historical side of Christianity.

In September 1906, shortly before his fifth birthday, Werner enrolled in a primary school in Würzburg. He spent three years at that school but then in 1909 his father was appointed Professor of Middle and Modern Greek at the University of Munich. In June 1910, a few months after his father took up the professorship, Werner and the rest of the family moved to Munich. There he attended the Elisabethenschule from September, spending only one year at this school before entering the Maximilians Gymnasium in Munich. This of course was the school where his grandfather was the headmaster.

In 1914 World War I began and the Gymnasium was occupied by troops. Lessons were arranged in different buildings and as a result of the disruption Heisenberg undertook much independent study which probably had a beneficial effect on his education. His best subjects were mathematics, physics and religion but his record throughout his school career was excellent all round. In fact his mathematical abilities were such that in 1917 he tutored a family friend who was at university in calculus. During this period he belonged to a paramilitary organisation which operated in the Gymnasium with the intention of preparing the young men for later military service.

Heisenberg also worked on farms as his contribution to another voluntary organisation which sent the boys to help in the fields in spring and summer. This work took him away from home for the first time in 1918 when he was sent to work on a dairy farm in Upper Bavaria. It was a time of great hardship with long hours of labour made worse since there was insufficient food. He spent his spare time playing chess, which he did to a very high standard, and also read mathematics texts he had taken with him. In fact by this time he had become interested in number theory and he read Kronecker's work and tried to find a proof of Fermat's Last Theorem.

After the war ended in 1918 the situation in Germany became unstable with different factions trying to take power by force. Heisenberg took part in the military suppression of the Bavarian Soviet forces but, although it was a very serious business, the young men probably treated it almost as a game. He later wrote [4]:-

I was a boy of 17 *and I considered it a kind of adventure. It was like playing cops and robbers ...*

In the Gymnasium Heisenberg led a youth movement and he later led a movement within the Young Bavarian League. In 1920 he took his Abitur examination and was one of two pupils entered from the Maximilians Gymnasium for a Bavarian wide competition for a scholarship from the Maximilianeum Foundation. Eleven scholarships were available and Heisenberg just made it by coming in eleventh place. His examination results in mathematics and physics were classed as extraordinary, but his essay on "tragedy as poetic art" was much less impressive. He declined the offer of free accommodation from the Foundation, preferring to live with his parents.

In the period between taking his Abitur examination and entering the University of Munich, Heisenberg went off hiking with his youth group. He nearly died of typhoid which he contracted after spending the night in a castle which had been used as a military hospital. He recovered, despite the problems of obtaining suitable food, in time to begin his university studies. During the summer of 1920 Heisenberg was, as he had been for some time, intending to study pure mathematics at university. He had read Weyl and also Bachmann's text which gave a complete survey of number theory and this was to be his intended research topic for his doctorate. He approached Ferdinand von Lindemann to see if he would be his research supervisor.

Had the interview with Lindemann been a success then Heisenberg might today be known as an outstanding number theorist. However, the interview did not go well, almost certainly since Lindemann was only two years off retiring and had only agreed to see Heisenberg as a favour to his father who was a friend and colleague. Following this Heisenberg had an interview with Sommerfeld who happily accepted him as a student.

With his fellow student Pauli, Heisenberg began to study theoretical physics under Sommerfeld in October 1920. At first he was cautious, taking mostly mathematics classes and making sure that he could revert to mathematics if the theoretical physics went badly. He avoided courses by Lindemann, however, so his mathematical interests moved from number theory to geometry. Soon his confidence in theoretical physics was such that by the second semester he was taking all of Sommerfeld's courses. He also took courses in experimental physics, which were compulsory, and he began to plan to undertake research in relativity. However Pauli, who was at that time working on his major survey of the theory of relativity, advised him against doing research in that topic. On atomic structure, however, Pauli explained, much needed to be done since theory and experiment did not agree.

In [6] Heisenberg wrote of his early days at university:-

My first two years at Munich University were spent in two quite different worlds: among my friends of the youth movement and in the abstract realm of theoretical physics. Both worlds were so filled with intense activity that I was often in a state of great agitation, the more so as I found it rather difficult to shuttle between the two.

In June 1922 he attended lectures by Niels Bohr in Göttingen. Returning to Munich, Sommerfeld gave him a problem in hydrodynamics to keep him busy while he (Sommerfeld) spent session 1922-23 in the United States. Heisenberg presented preliminary results on the problem on turbulence at a conference in Innsbruck before going again to Göttingen to study with Born, Franck, and Hilbert while his supervisor was away. There he worked with Born on atomic theory, writing a joint paper with him on helium. His doctoral dissertation, presented to Munich in 1923, was on turbulence in fluid streams.

After taking his doctorate Heisenberg went on a trip to Finland then, in October 1923, he returned to Göttingen as Born's assistant. In March 1924 he visited Niels Bohr at the Institute for Theoretical Physics in Copenhagen where he met Einstein for the first time. Returning again to Göttingen he delivered his habilitation lecture on 28 July 1924 and qualified to teach in German universities.

Heisenberg later wrote:-

I learned optimism from Sommerfeld, mathematics at Göttingen, and physics from Bohr.

From September 1924 until May 1925 he worked, with the support of a Rockefeller grant, with Niels Bohr at the University of Copenhagen, returning for the summer of 1925 to Göttingen. Heisenberg invented matrix mechanics, the first version of quantum mechanics, in 1925. He did not invent these concepts as a matrix algebra, however, rather he focused attention on a set of quantised probability amplitudes. These amplitudes formed a non-commutative algebra. It was Max Born and Pascual Jordan in Göttingen who recognised this non-commutative algebra to be a matrix algebra.

Matrix mechanics was further developed in a three author paper by Heisenberg, Born and Jordan published in 1926. In May 1926 Heisenberg was appointed Lecturer in Theoretical Physics in Copenhagen where he worked with Niels Bohr. In 1927 Heisenberg was appointed to a chair at the University of Leipzig and he delivered his inaugural lecture on 1 February 1928. He was to hold this post until, in 1941, he was made director of the Kaiser Wilhelm Institute for Physics in Berlin.

In 1932 he was awarded the Nobel Prize in physics for:-

The creation of quantum mechanics, the application of which has led, among other things, to the discovery of the allotropic forms of hydrogen.

In the presentation speech H Pleijel said:-

Heisenberg ... viewed his problem, from the very beginning, from so broad an angle that it took care of systems of electrons, atoms, and molecules. According to Heisenberg one must start from such physical quantities as permit of direct observation, and the task consists of finding the laws which link these quantities together. The quantities first of all to be considered are the frequencies and intensities of the lines in the spectra of atoms and molecules. Heisenberg now considered the combination of all the oscillations of such a spectrum as one system, for the mathematical handling of which, he set out certain symbolical rules of calculation. It had formerly been determined already that certain kinds of motions within the atom must be viewed as independent from one another to a certain degree, in the same way that a specific difference is made in classical mechanics between parallel motion and rotational motion. It should be mentioned in this connection that in order to explain the properties of a spectrum it had been necessary to assume self-rotation of the positive nuclei and the electrons. These different kinds of motion for atoms and molecules produce different systems in Heisenberg's quantum mechanics. As the fundamental factor of Heisenberg's theory can be put forward the rule set out by him with reference to the relationship between the position coordinate and the velocity of an electron, by which rule Planck's constant is introduced into the quantum-mechanics calculations as a determining factor. ...

Heisenberg's quantum mechanics has been applied by himself and others to the study of the properties of the spectra of atoms and molecules, and has yielded results which agree with experimental research. It can be said that Heisenberg's quantum mechanics has made possible a systemization of spectra of atoms. It should also be mentioned that Heisenberg, when he applied his theory to molecules consisting of two similar atoms, found among other things that the hydrogen molecule must exist in two different forms which should appear in some given ratio to each other. This prediction of Heisenberg's was later also experimentally confirmed.

Heisenberg is perhaps best known for the *Uncertainty Principle*, discovered in 1927, which states that determining the position and momentum of a particle necessarily contains errors the product of which cannot be less than the quantum constant h. These errors are negligible in general but become critical when studying the very small such as the atom. It was in 1927 that Heisenberg attended the Solvay Conference in Brussels. He wrote in 1969:-

To those of us who participated in the development of atomic theory, the five years following the Solvay Conference in Brussels in 1927 *looked so wonderful that we often spoke of them as the golden age of atomic physics. The great obstacles that had occupied all our efforts in the preceding years had been cleared out of the way, the gate to an entirely new field, the quantum mechanics of the atomic shells stood wide open, and fresh fruits seemed ready for the picking.*

Heisenberg published *The Physical Principles of Quantum Theory* in 1928. In 1929 he went on a lecture tour to the United States, Japan, and India. In the 1930s Heisenberg and Pauli used a quantised realisation of space in their lattice calculations. Heisenberg hoped this mathematical property would lead to a fundamental property of nature with a 'fundamental length' as one of the constants of nature.

In 1932 Heisenberg wrote a three part paper which describes the modern picture of the nucleus of an atom. He treated the structure of the various nuclear components discussing their binding energies and their stability. These papers opened the way for others to apply quantum theory to the atomic nucleus.

In 1935 the Nazis brought in a law whereby professors over 65 had to retire. Sommerfeld was 66 and he had already indicated that he wanted Heisenberg to succeed him. It was an appointment which Heisenberg badly wanted and in 1935 Sommerfeld again indicated that he wanted Heisenberg to fill his chair. However this was the period when the Nazis wanted "German mathematics" to replace "Jewish mathematics" and "German physics" to replace "Jewish physics". Relativity and quantum theory were classed as "Jewish" and as a consequence Heisenberg's appointment to Munich was blocked. Although he was in no way Jewish, Heisenberg was subjected to frequent attacks in the press describing him to be of "Jewish style".

In 1937 Heisenberg married Elisabeth Schumacher. He met her through his music which was important to him throughout his life. An excellent pianist, Heisenberg met Elisabeth Schumacher at a concert in which he was performing at the house of a friend. Elizabeth was only 22 when they met, Heisenberg was 35. They were married on 29 April 1937, less than three months after they first met. Heisenberg had been asked to take up the appointment at Munich in March but had asked for the date to be delayed until August because of his wedding. It was agreed that he should take up the appointment on 1 August. He and his wife arrived in Munich in July but his appointment was blocked by the Nazis.

During the Second World War Heisenberg headed the unsuccessful German nuclear weapons project Uranverein. He worked with Otto Hahn, one of the discoverers of nuclear fission, on the development of a nuclear reactor but failed to develop an effective program for nuclear weapons. Whether this was because of lack of resources or a lack of a desire to put nuclear weapons in the hands of the Nazis, it is unclear.

After the war he was arrested by Alsos, a secret mission that followed the advancing Allied forces in Europe to determine the progress of Germany's atomic bomb project. He was interned at Farm Hall in Godmanchester, Huntingdonshire, England, with other leading German scientists. However he returned to Germany in 1946 when he was appointed director of the Max Planck Institute for Physics and Astrophysics at Göttingen. In the winter of 1955-1956 he gave the Gifford Lectures "On physics and philosophy" at the University of St Andrews. When the Max Planck Institute moved to Munich in 1958 Heisenberg continued as its director. He held this post until he resigned in 1970.

He was also interested in the philosophy of physics and wrote *Physics and Philosophy* (1962) and *Physics and Beyond* (1971).

Heisenberg received many honours for his remarkable contributions in addition to the Nobel Prize for Physics. He was elected a Fellow of the Royal Society of London, and was a member of the academies of Göttingen, Bavaria, Saxony, Prussia, Sweden, Rumania, Norway, Spain, The Netherlands, Rome, the Akademie der Naturforscher Leopoldina, the Accademia dei Lincei, and the American Academy of Arts and Sciences. Among the prizes he received was the Copernicus prize.

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