obituary

Werner Heisenberg died on February 1, 1976. His youth was inspired; he lived through a long war which destroyed cities, lives and the spirit of people; in his old age he tried to rebuild a great tradition which had been virtually wiped out by Hitler.

The beginning of this century was the most remarkable period in the history of science. It was, in fact, so revolutionary that most people, including the majority of intellectuals, have failed to grasp what has happened. The leaders of this revolution were Heisenberg and his great teacher, Niels Bohr. The result was a complete explanation of the world of the atom. This fact is known. But the philosophical implications are all but forgotten. The philosophical principle is called 'Complementarity'.

Complementarity, or its older designation, dualism, is not new. It is as old as man. What are you: a piece of matter or a soul? It is difficult to deny etiher body or spirit. But to believe in both was considered sheer mysticism by a generation of scientists who lived in a world in which truth seemed to be simple.

It was Bohr who introduced a peculiar element into the most straightforward of all experimental sciences, physics. He based his quantum theory not on an explanation but on a contradiction. His ideas caused consternation, but his successes could not be denied.

Heisenberg, barely 24 years old, created order where there seemed to be chaos. Where Bohr navigated a new ocean keeping the shore of classical physics in sight by the use of the correspondence principle, Heisenberg left the old land and sailed beyond the point of no return. He found the New World of quantum mechanics. (It is even more remarkable that in inventing 'matrix mechanics' he did not know anything about matrices—he reinvented them.)

The unity of physics was reestablished by the cooperation of Heisenberg and Bohr. They asked the essential question: are atoms made of waves or particles? The answer: we cannot explain atoms without using both the wave picture and the particle concept. The two can be reconciled by setting limits to the accuracy in applying either description. For instance, the more accurately we know the position of a particle the less accurately can we know its velocity (or momentum). This is Heisenberg's 'Uncertainty Relation'. His first illustration was based on the resolving power of the microscope, a point on which, amusingly, he was ignorant at his PhD examination.

What has this to do with the body–spirit dualism? Heisenberg has shown that two obviously contradictory concepts, waves and particles, are not only necessary in explaining the structure of atoms but also, these two concepts can co-exist within a single rigorous mathematical formalism. If this can be done today for atoms why should it not become possible to do something

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similar someday in describing life or even a human being? Whether anything of the kind will happen one cannot tell. But Bohr and Heisenberg did something which even in the context of the great intellectual accomplishments of modern science is quite exceptional.

One often has the feeling that discoveries are just waiting to be made. Most scientists, even the great ones, merely accelerate science. They don't change it. Bohr and Heisenberg gave a completely new turn to the understanding of the world. Without them this understanding may never have come, at least not in our present culture. (This may sound like an exaggeration but I remember Bohr's statement: "If I can't exaggerate, I can't talk.") Without them the science of the atoms may have developed into a formalism even more remote from the common, unmathematical understanding than it is today. Without them the intricate concept of the interaction between the observer and the object may have been missed. (Heisenberg modestly denied this; he said that he only found what was there.)

Of course, the prime mover was Bohr. He was far ahead of everybody, but he was obscure, almost oracular. It was Heisenberg who brought the wisdom of Bohr (which Bohr managed to hide in his own words) to the level of lucidity where the common-or-garden theoretical physicist and mathematician could understand it, if he tried.

But in performing this translation of philosophy to exact science, Heisenberg did not lose any of the great original concepts. The philosophy (not coming from a philosopher) might have been lost. The science will survive. This is why Heisenberg is one of the few who have truly changed the world. It can never change back.

Heisenberg was made a professor when he was 26, and I became one of his students. We all talked physics, and played ping-pong and chess, and in this close environment a lot of fundamental work was done. Heisenberg received the Nobel prize in 1932 for the historic discovery of quantum mechanics and its implications, but much of his additional work would have sufficed in its own right to earn that distinguished honour. Some milestones are: papers on quantum field theory (QED with Pauli (1929, 1930) and divergence problems (1934)—Heisenberg's positivism can be exaggerated!), work on the solid state (the first understanding of ferromagnetism (1928)) and on symmetries (the distinction between ortho- and para-helium and hydrogen) and the invention of iospin (1932). We knew that the world was open and the key was reason.

Then came Hitler and reason was no more. In the summer of 1939, Heisenberg visited the US. Several of us asked him to stay. His answer to me was: "If your brother had stolen a silver spoon, he is still your brother." It was much more than a silver spoon. Both of us knew it, but neither of us could say so.

During the war Heisenberg worked on atomic energy. He used his position to save the lives of several fellow physicists. In his project he got nowhere. Why was Heisenberg unsuccessful in his wartime job? I am sure that the reason was not any lack of ability. I believed firmly that the obstacle was the silver spoon.

In his last years he wrote the story of his great experiences in science and the story of the tragedy of the deeply troubled times in Germany. In his writings, it becomes clear why Heisenberg failed during the war. He was happy to see that the technical difficulties were enormous and he concentrated on peaceful reactors. He only hoped that the American scientists, including the refugees from Europe, would come to the same conclusion. In 1941 he visited Bohr to give him this message. But Bohr's ears were closed and Heisenberg knew that he must continue to live in a small island surrounded by the Nazi horror; the greater world was too far away; even his best friend had turned his back. Bohr later escaped to the US, but Heisenberg's message was never delivered.

I shall not forget one of Heisenberg's recollections. With a colleague, he is hurrying through burning Berlin, trying to get back to two of his sons when his shoe catches fire. And while he puts out the fire, he discusses with his friend how science will be rebuilt in Germany when the catastrophe has run its course.

Shortly after the defeat of Germany, he hears of Hiroshima. He can hardly believe it. He is convinced that a political movement, or country, must be judged by its methods, not by its professed aims. (Heisenberg never mentions a nightmare which must have occurred to him: what would have happened if atomic bombs had been used against Germany. Hitler, unlike Hirohito, would not have had the fortitude to surrender. Hitler wanted Germany destroyed if the war was lost.)

But at last peace came and the reconstruction started. Heisenberg returned to the land he loved most, Bavaria. He continued to work on the hardest and most exciting problems of physics. The same basic philosophy that had led him to his formulation of quantum mechanics took him to the S-matrix approach to particle physics (1946). He later devoted himself to a bold attempt to understand particle physics through non-linear field theories with an inherent 'length' scale—continuing, in fact, pre-war ideas. This expressed his opposition to the idea that there are never-ending hierarchies of successively more fundamental particles— the 'big fleas–lesser fleas' syndrome. He also initiated the German programme for the production of nuclear energy.

In a long, magnificent and difficult life he never lost his sense of purpose, nor a sense of humour. On the 800th anniversary of the Bavarian state, he appeared on television and said: "The Bavarian unites the discipline of the Austrian with the charm of the Prussian." Most particularly, he retained a sense of balance. To each serious argument, he attached its opposite. He understood, from his own physics that between 'yes' and 'no' there are possible answers, less abrupt and more fruitful.

I am one of the relatively few who had a teacher like Heisenberg. From his life there remain for me two lessons. One is that the cataclysm of yet another world war must be avoided. Next time, though man will surely survive, it will be even more difficult to imagine how the spirit can be resurrected. The other is that the path of peace is not only difficult but also uncertain. No simple proposal, neither power nor appeasement, will suffice.

The title of Heisenberg's memoirs *Der Teil und das Ganze* means literally the part and the whole: the world cannot be divided into science and politics, nor into any other components. It is strange and wonderful that this lesson of unity should have been taught by a physicist who worked on a subject that most consider remote from the common understanding.

Edward Teller

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