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WAS BORN

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THE PLACES WHERE QUANTUM MECHANICS WAS BORN

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I was asked to say a few words about the schools of theoretical physics before the second world war. Let me restrict myself to the schools that contributed to quantum mechanics *)

The achievement of Q.M. was the result of the effort of many scientists, in contrast to the theory of relativity. But there was a center of this development: Copenhagen with Niels Bohr as the leading figure. Almost every year a conference was held there, and many of the most active theorists spent shorter or longer intervals of time there, presenting and discussing their ideas with Bohr in their unfinished form. There was no place better to discuss half-baked ideas and to be put on the right track by Bohr and his collaborators. Much more of the fundamental ideas of Q.M. can be traced to those fertile conversations than the literature seems to indicate. Bohr only rarely has put his name on the papers.

This is why in the Figure, the most important schools of theoretical physics that contributed to quantum theory are arranged in a circle around Copenhagen. The Figure indicates the names of the most active theorists at these places. Some persons are found at more than one place because they moved from one to the other.

Let me say a few words about the different centers. In Munich, A. Sommerfeld created a graduate school where an incredible number of outstanding physicists received their education. The figure mentions the most important ones. He was a master teacher who knew how to inspire his pupils by giving them challenging tasks. His own contributions to Q.M. stretch from 1911 to the thirties. He developed the early quantum theory of atoms after Bohr's famous paper, he contributed much to understand atomic spectra, he found the relativistic corrections to the hydrogen spectrum, and he developed the quantum theory of electrons in metals.

The real Q.M. started with De Broglie's ingenious idea about the wave nature of particles, in 1924. Other French contributions were also quite important: Langevin about magnetism, Brillouin about metals, and Proca's extension of wave mechanics to particles of spin 1. For reasons that are not quite clear, the contact of the Paris theorists with Copenhagen were more tenuous than that of other centers.

Perhaps the most important center besides Copenhagen was Göttingen. A large group worked there and many of the leading ideas were conceived by the collaboration of Born, Heisenberg, Jordan and Hund. Heisenberg shuttled between Copenhagen and Göttingen, bringing ideas from one place to the other. Thus during the few years 1925-27 the foundations of Q.M. were created between those two centers, with important inputs from other places, such as Schrödinger in Zürich and Dirac in England. A slight variation of Churchill's statement about the Royal Air Force is in place here: "Never have so few done much in such a short time". Also in Göttingen originated the Heitler-London theory of the molecular bound.

*) Q.M. is the abbreviation of quantum mechanics.
Zürich was already mentioned as the place where Schrödinger developed his pioneering equation (with the help of H. Weyl). Later on, Pauli came to Zürich and contributed many important ideas with his assistants (named in the Figure), always in close contact with Copenhagen and with Heisenberg. With the latter he created the basis of modern field theory.

The Leipzig center was active since Debye moved there but it took a special significance when Heisenberg was appointed. Debye and Hückel developed quantum chemistry and Heisenberg with Bloch were able to explain ferromagnetism. It was from Leipzig that Heisenberg corresponded with Pauli and laid the foundations of field theory.

The towering figures in Berlin were Einstein and Planck. Wigner worked at that time at Haber’s Institute in Dählem, where he developed many of his fundamental ideas about Q.M. and group theory in the late twenties and early thirties. J. von Neumann wrote his influential book on the foundations of Q.M., Schrödinger came from Zürich in 1927, continuing his work on Q.M., especially the connection with relativity. There was much contact between Berlin, Göttingen and Copenhagen.

The English theorists were mostly concentrated in Cambridge. The towering figure was P. Dirac. Like Einstein, he produced three pioneering papers within one year (1926-27): his new formulation of Q.M., his relativistic wave equation, and his paper on the quantum theory of radiation. Dirac worked mostly by himself—he had very few “students”—but he was in very close contact with Copenhagen. He frequently visited there and had mutually stimulating discussions with Bohr and his collaborators. Darwin and Fowler contributed much to the development of ideas concerning the relativistic wave equation and quantum statistics. Larmor’s contributions to magnetism are well known, and so is Mott’s work on the theory of metals. The Thomas precession of the spinning electron originated there.

The Netherlands have an old tradition of pioneers in theoretical physics. The grand old man was H.A. Lorentz. P. Ehrenfest, his successor, created an inspiring school of physicists, such as Uhlenbeck and Goudsmit, the discoverers of the spin, and H. Casimir who also worked in Copenhagen and Zürich. One of the main interests of this school was statistical mechanics and its relation to Q.M.

The center in Rome was, of course, under the intellectual leadership of Fermi. But Majorana, a rather independent character, contributed much to our understanding of Q.M., especially the special role of the neutrino. How much more would he have created if his life had not ended so early! Racah developed important tools for the systematics of atomic and nuclear spectra.

There were active centers further away from central Europe. We have the Soviet Union with the leading theorists Landau, Gamow, Tamm, Frenkel and Fock who contributed much to the intellectual edifice of Q.M. At that time, it was much easier to travel to the West than today. All of the above named theorists have spent much time in Copenhagen and other centers. Frenkel and Tamm have done much for the application of Q.M. to material science, Fock for the formulation of many-body problems, Gamow for the understanding of α-decay, and Landau’s critical and penetrating spirit has helped so many times to a better understanding of Q.M., and its applications to other fields of physics.

In Japan Yukawa and Nishina played leading roles and frequently visited Copenhagen. Fujikawa worked with Heisenberg in Leipzig. Later, Tomonaga was a leading figure in the development of quantum electrodynamics.

Finally, there is the US that played an important role, though not as important as after the mid-thirties. Van Vleck was a pioneer in the application of Q.M. to the theory of magnetism, Kemble and Slater were deeply involved in the early development of Q.M. Slater was one of the important creators of the theory of the solid state. In the earlier days of Q.M., both Slater and Oppenheimer spent much time at different centers in Europe.
The twenties and early thirties were often called the Golden Years of Physics. It certainly is true that our thinking about nature has rarely changed so much as it did during those years. Let me end with a quote by Henri Poincaré (1912):

"Il est à peine nécessaire de faire remarquer combien la théorie des quanta s'écarte de tout ce que l'on avait imaginé jusqu'ici ; ce serait sans aucun doute la plus grande et la plus profonde révolution que la philosophie naturelle ait subie depuis Newton."
Schools of theoretical physics in the years of the foundation of QM

Abbreviations

G - Göttingen, M - Munich, L - Leipzig, Z - Zurich, R - Rome,
P - Paris, SU - USSR, J - Japan, US - USA, C - Cambridge (UK)
NL - Holland, B - Berlin, K - Copenhagen.