The Marvel and the Mystery of Quantum Mechanics – Some Reflections

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Quantum Theory born on Sunday, October 7, 1900

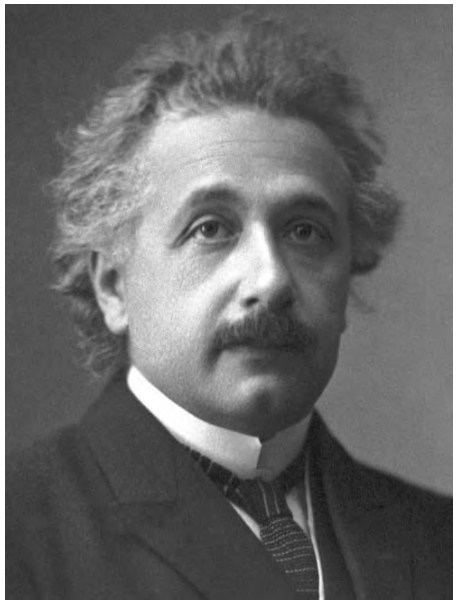
Planck formula, and later derivation: dependence of energy density of black body radiation on frequency and temperature.

Appearance of Planck's constant, quantisation of energy.

1900–1924 Period of the Old Quantum Theory – mainly led by Albert Einstein from 1905, Niels Bohr from 1913.

Statistical properties of radiation, photon concept, wave particle duality for light and later for matter, laws of spectroscopy, stability of matter, structure of Periodic Table based on Rutherford's nuclear atom model.

M. Planck



A. Einstein

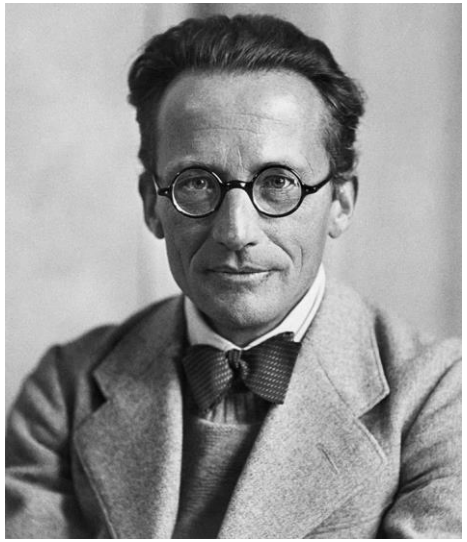
N. Bohr

1925–1927 Creation of Quantum Mechanics by W. Heisenberg, P. A. M. Dirac, E. Schrodinger

“Never in the history of physics has so much been achieved by so few in such a short time”.

W. Heisenberg

P. A. M. Dirac



E. Schrodinger

"…. one evening I … was ready to determine the individual terms … in the energy matrix, by… an extremely clumsy series of calculations. When the first terms seemed to accord with the energy principle, I became … excited, and began to make countless arithmetical errors. … it was almost three o'clock in the morning before the final result of my computations lay before me. The energy principle had held…, and I could no longer doubt the mathematical consistency and coherence of the kind of quantum mechanics to which my calculations pointed. … I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I now had to probe this wealth of mathematical structures nature had so generously spread out before me." – Heisenberg

Mathematical structure of QM first, physical interpretation later. Physical properties of a system, numbers classically, non numerical in QM, abstract mathematical symbols. Description of states also more subtle than before.

Key components of interpretation – Born Rule for probabilities and measurement results (1926);

Uncertainty Principles and Complementarity Principle (1927).

"… nature works on a different plan. Her fundamental laws do not govern the world as it appears in our mental picture in any very direct way, but instead they control a substratum of which we cannot form a mental picture without introducing irrelevancies." – Dirac

"The main object of physical science is not the provision of pictures, but is the formulation of laws governing phenomena and the application of these laws to the discovery of new phenomena. If a picture exists, so much the better, but whether a picture exists or not is a matter of only secondary importance. In the case of atomic phenomena no picture can be expected to exist in the usual sense of the word 'picture', by which is meant a model functioning essentially on classical lines." – Dirac

Konrad Lorenz – Max Delbruck: human capacities and abilities shaped by evolution

to deal with limited part of world ⟶ domain of classical physics.

Early years – emphasis on applications of quantum mechanics

"There is no part of chemistry that does not depend, in its fundamental theory, upon quantum principles." – Linus Pauling

Einstein's concerns: initially at the level of wave particle duality and Uncertainty Principles – QM incorrect.

"To the question 'Is the electron a particle or is the electron a wave?', quantum mechanics gives the triumphant answer: 'Yes!'."

Later view: QM correct but incomplete

1935 Einstein–Podolsky–Rosen paper (EPR) – definitions of realism, locality.

Argued that QM needs to be extended – using hidden variables.

Quantum revolution in two parts: Wave Particle Duality (upto 1930); then Entanglement

(1935 onwards, 1960's to now)

1932 von Neumann theorem – impossible to extend QM

1952 David Bohm – explicit realist form of Non Relativistic QM.

1964 John Stewart Bell – critical analysis – made EPR ideas experimentally testable.

David Bohm

J. S. Bell

Combining QM with Shannon's 1948 theory of classical information

Quantum Information Science, Quantum Computation

No-cloning, Teleportation

Steven Weinberg, 'The Trouble with Quantum Mechanics', New York Review of Books, 2017

Two options – Instrumentalist approach, Realist approach

"The mathematical theory of probability is an attempt to make as objective as possible a purely subjective idea". – W. Pauli

"…it was not possible to formulate the laws of quantum mechanics in a fully consistent manner without reference to the consciousness", – E. P. Wigner

"… the genuine adherents of the relative-state ("many worlds") and mentalistic ("reduction-by-consciousness") interpretations of quantum mechanics".

– A. J. Leggett and A. Garg

"…my own suspicion is that the Universe is not only queerer than we suppose, but queerer than we can suppose." – J. B. S. Haldane