The Doctrine of Classical Concepts in Historical Perspective

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Why Classical Concepts?

You have repeatedly expressed you definite conviction that measurements must be described in terms of classical concepts... There must be clear and definite reasons which cause you repeatedly to declare that we must interpret observations in classical terms, according to their very nature... it must be among your firmest convictions – and I cannot understand what it is based upon.

Schrödinger to Bohr, 13 October 1935
Bohr and the Indispensability of Classical Concepts

It lies in the nature of physical observation … that all experience *must* ultimately be expressed in terms of classical concepts.

N. Bohr, *Atomic theory and the description of nature* (1934)

The unambiguous interpretation of any measurement *must be* essentially framed in terms of classical physical theories, and we may say that in the sense the language of Newton and Maxwell will remain the language of physics for all time.

N. Bohr, ‘Maxwell and modern theoretical physics’ (1931)

It is decisive to recognize that, *however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms*. The argument is simply that by the word ‘experiment’ we refer to a situation where we can tell others what we have done and what we have learned and that, therefore, the account of the experimental arrangement and of the results of the observations must be expressed in unambiguous language with suitable application of the terminology of classical physics.

N. Bohr, ‘Discussion with Einstein on epistemological problems in atomic physics’ (1949)
Outline

- Bohr’s doctrine of classical concepts
- The Bohr-Heisenberg disagreement over the cut in 1935
- The evolution of the doctrine of classical concepts in the 1950s-60s
The alliance between Kantians and physicists was premature in Kant's time, and still is; in Bohr, we begin to perceive its possibility.

C. F. v. Weizsäcker, 1966

[Bohr's concept of complementarity] is the first example of a precise dialectical [materialist] scheme.

L. Rosenfeld, 1953

[Bohr's viewpoint] is entirely compatible with the formulations of logical empiricism.

P. Frank, 1947.

Traditional philosophy has accustomed us to regard language as something secondary and reality something primary. Bohr considered this attitude toward the relation between language and reality inappropriate.

A. Petersen, 1963
Bohr and the Philosophy of Experiment

- Bohr as a *philosopher of experiment*
- Bohr’s emphasis on the *functional*, as distinct from a *structural*, description of experiment
- The object-instrument divide
- The epistemological problem of quantum mechanics
The Epistemological Problem

A still further revision of the problem of observation has since been made necessary by the discovery of the universal quantum of action... This circumstance, at first sight paradoxical, finds its elucidation in the recognition that it is no longer possible sharply to distinguish between the autonomous behavior of a physical object and its inevitable interaction with other bodies serving as measuring instruments, the direct consideration of which is excluded by the very nature of the concept of observation itself.

N. Bohr, ‘Causality and complementarity’, (1937)

We are faced here with an epistemological problem quite new in natural philosophy, where all description of experiences so far has been based on the assumption ... that it is possible to distinguish sharply between the behaviour of objects and the means of observation.

[W]e are, therefore forced to examine more closely the question of what kind of knowledge can be obtained concerning objects. In this respect, we must on one hand, realize that the aim of every physical experiment – to gain knowledge under reproducible and communicable conditions – leaves us no choice but to use everyday concepts, perhaps refined by the terminology of classical physics, not only in accounts of the construction and manipulation of measuring instruments but also in the description of actual experimental results.

N. Bohr, ‘Natural Philosophy and Human Cultures’ (1937)
Bohr’s transcendental argument

- The object-instrument distinction is a condition of possibility for a device to serve its *epistemological purpose* as instrument, in spite of the fact that according to quantum mechanics, the instrument and object are in an entangled state.

- The *functioning* of the experimental apparatus is founded on the assumption that the interaction between an instrument and an object (even when making a measurement of a non-classical observable like spin) is a *causal* interaction taking place somewhere in *space* and *time* – essentially an exchange of energy/momentum in space-time.

- This is not a question about the nature of reality (ontology), but what are the conditions of possibility of experimental inquiry (epistemology).
Challenges in the 1930s


[I]n a mathematical treatment of the process, a dividing line must be drawn between, on the one hand, the apparatus … and on the other hand, the physical system we wish to investigate. The latter we represent mathematically as a wave function. This function, according to quantum theory, consists of a differential equation which determines any future state from the present state of the function…The dividing line between the system to be observed and the measuring apparatus is immediately defined by the nature of the problem but it obviously signifies no discontinuity of the physical process. For this reason there must, within certain limits, exist complete freedom in choosing the position of the dividing line.

W. Heisenberg, ‘Prinzipielle Fragen der modernen Physik’ (1936)
The Bohr-Heisenberg Correspondence

I have experienced difficulties in trying to understand more clearly the argumentation in your article. For I am not quite sure that I fully understand the importance you attach to the freedom of shifting the cut between the object and the measuring apparatus. Any well-defined quantum-mechanical problem must be concerned with certain classically described experimental setting, and if one changes the kind or use of the measuring instruments, and thus the [experimental] setting, the phenomenon will always change completely. I therefore believe that for a given experimental setting the cut is determined by the nature of the problem.

Bohr to Heisenberg, 15 September 1935
Bohr has emphasized that it is more realistic to state that the division into the object and rest of the world is not arbitrary [but is determined by the very nature of the experiment].


Bohr and I could not agree on] whether the cut between that part of the experiment which should be described in classical terms and the other quantum-theoretical part had a well defined position or not… I argued that a cut could be moved around to some extent while Bohr preferred to think that the position is uniquely defined in every experiment.

Heisenberg to Heelan, 1975
The historical context – a new wave of criticisms and misunderstandings:
• Bohm’s hidden variables theory (1952)
• De Broglie’s reconversion to a causal theory program (1953)
• Everett relative-state interpretation (1957)
• The Soviet critique of the Copenhagen interpretation (1950s)
• Wigner's subjectivist reading of von Neumann (1961-3)

The thermodynamic program – condition of irreversibility
• Ludwig (1955)
• The Copenhagen school’s exchange with Wheeler and Everett (1957-8)
• Prosperi, Loinger and Saleri (1962)
• Rosenfeld (1965)

It is understandable that in order to exhibit more directly the link between the physical concepts and their mathematical representation, a more formal rendering of Bohr's argument should be attempted.
Having thus accepted the falsity of classical physics, taken literally, we must ask how it can be explained as an essentially good approximation. This amounts to asking what physical condition must be imposed on a quantum-theoretical system in order that it should show the features which we describe as ‘classical’. My hypothesis is that this is precisely the condition that it should be suitable as a measuring instrument. If we ask what that presupposes, a minimum condition seems to be that irreversible processes should take place in the system… I am unable to prove mathematically that the condition of irreversibility would suffice to define a classical approximation, but I feel confident it is a necessary condition.

Even in large dimensions there are many solutions of the quantum-mechanical equations to which no analogous solutions can be found in classical physics. In these solutions the phenomenon of the ‘interference of probabilities’ would show up… Therefore, even in the limit of large dimensions the correlation between the mathematical symbols [of quantum mechanics] … and the ordinary [classical] concepts is by no means trivial. In order to get at such an unambiguous correlation one must take another feature of the problem into account. It must be observed that the system, which is treated by the methods of quantum mechanics is in fact a part of a much bigger system (eventually the whole world)… The interaction with the bigger system with its undefined microscopic properties then introduces a new statistical element into the description … of the system under consideration. In the limiting case of the large dimensions this statistical element destroys the effects of the ‘interference of probabilities’ in such a manner that the quantum-mechanical scheme really approaches the classical one in the limit.

The role of decoherence is to establish a boundary between quantum and classical. The boundary is in principle moveable, but in practice largely immobilized by the irreversibility of the process of decoherence… The equivalence between ‘macroscopic’ and ‘classical’ is then validated by the decoherence considerations, but only as a consequence of the practical impossibility of keeping objects which are macroscopic perfectly isolated.


Wheeler was absolutely essential in defining the problem, or rather, the whole set of problems [in the1970s and 80s which led to the development of decoherence].


Zurek developed his term paper for Wheeler’s seminar on the two-slit experiment:
W. Wooters & W. Zurek, ‘Complementarity in the double-slit experiment: quantum nonseparability and a quantitative statement of Bohr’s principle’ (1979)