# THE PHILOSOPHY OF THE COPENHAGEN INTERPRETATION

The Compenhagen Interpretation of the wave-particle duality attempts to overcome the conceptual dilemma by taking the attitude that certain concepts in their classical sense are not contradictory but complementary in the sense that together they 'exhaust' the description of the phenomena under observation. " For this purpose it is decisive to recognise that however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be in classical terms.[1] All evidence must of necessity be expressed in classical terms but as in the case of quantum theory these concepts are to be used in a non-classical sense.

Bohr says, " We must renounce ascribing conventional physical attributes to micro-objects in an absolute way."[2] The application of the word " phenomena " i.e. what is under study, is now restricted " exclusively to refer to the observations obtained under specified circumstances including an account of the whole experimental arrangement."[3] It is asserted that this new definition of the concept of phenomena contains no arbitrary element but ". . . . is a part of the terminology inherent in quantum theory and expressing a situation of fact, i.e. a situation which is not of our doing, but which we have learned from experience ".[4]

An important principle, the Correspondence Principle, states that in the regions where the quantum of action ( h ) is negligible the laws of quantum theory are the same as those of classical physics. This principle which forms a bridge between classical and quantum theories is necessitated in the Copenhagen Interpretation ( henceforth C. I. ) because of the 'demand' that classical concepts be used to describe all experience. Classical concepts, within the framework of which the quantum of action cannot be comprehended, can, it is claimed, be reconciled to the quantum of action if a more 'liberal attitude towards these concepts '[5] is adopted. The Correspondence Principle, which according to Bohr arises out of regarding quantum theory as a 'rational generalisation of classical theories '[6], is thus based on the understanding that because of the smallness of the quantum of action, the classical concepts, if handled with caution, can be considered adequate to describe and explain the new experience. Allowing for the quantum of action, these concepts can be used in a manner which permits the description of any conceivable experiment in classical terms, so long as it leads to correct predictions.

For any such " rational generalisation " of classical physics, the wave-particle duality has to be considered a basic feature. Consequently, the wave and particle concepts are now to be used in their respective fields for their predictive use. The paradoxes that are given rise to by giving them a realistic interpretation are taken care of by stripping such concepts of this interpretation at least in the microscopic domain. This is done by introducing the stipulation that an observable be considered to exist in a system when, and only when, an observation of it is being made.

The concepts now cease to denote attributes of the system but fulfil 'their true logical function' which is " to express *relations* between the system and certain apparatus of entirely classical (i.e. directly controllable) character which serve to fix the conditions of observation and register the results. "[7]

Classical concepts are now regarded as 'expedients which enable us to express, in a consistent manner, essential aspects of the phenomena '[8] free from any realistic interpretation.

Since a separation, even conceptually, of the " observed " and the " observer " is impossible, Heisenberg's Uncertainty Relations are neither theoretical nor objective. They can neither be surmounted by a theory at a deeper level, nor are they inherent in nature, for an autonomous world without observation is now " meaningless ". They can only be interpreted as empirical indeterminacies which are irreducible and incontrollable traits of the results of observation.

The problem of explaining the states of two interacting systems is resolved by Bohr in a similar manner. During the interaction of A and B, the dynamical states of both A and B cease to be well-defined so that it becomes " meaningless ", rather than " false " to ascribe a definite energy to them.[9]

" There is an undeniable similarity between the epistemological conclusion drawn in such a straightforward, unambiguous way from the peculiar character of the quantum laws, and the insistence of the early positivists on the essential part played by our sensations in determining our knowledge of the external world. This only means that, to that extent, the early positivist movement was a healthy reaction against the shallow metaphysics of mechanistic materialism. But why should scientists be made responsible for the later positivists' blundering into a metaphysics of their own ? "[10]

Rosenfold's remarks make it essential to examine the use of the word " meaningless ". Does it contain any reference to our knowledge or observability ? Does it mean that intermediate states cannot be asserted to exist because they are not observed ? Does it refer only to the absence of predictability ? The term, used in any of these senses, leads to implications which are dangerously close to the philosophy of positivism.

Feyerabend tries to attach a physical meaning to " meaninglessness " and warns us against drawing any positivist conclusions from it, which according to him, are not intended in Bohr's assertion; though he concedes that Heisenberg and others have adopted precisely this conclusion.[11] According to him it is not the term " meaningless ", which leads to non-existence because of non-observability; it is the non-existence itself that is posited in Bohr's assertion. We shall show that this " non-existence " is a consequence of the positivist verification principle and its criterion of observability. Even if we concede Bohr's good intentions as a " realist " or " materialist ", which Professor Feyerabend stresses, positing the non-existence of intermediate states, cannot save us from positivism.[12] For, if the non-existence of intermediate states is *a fact*, by itself, what is implied is an idealism greater than the idealism of positivism.

The question of the existence of micro-objects is rejected as " meaningless " where no empirical verification is possible even in principle. In the case of Bohr's assertion, the term " meaningless", in relation to the ascribing of definite energy to interacting states of a system, is used in the same sense. The inability to ascribe definite energies, i.e. the inability to find empirical verification for such states, is termed meaningless because such verification is " in principle " not possible.

Once the problem of intermediate states is overcome by postulating their non-existence the entire system of quantum mechanics as interpreted by Bohr becomes consistent. These problems arise only when we try to give a rational account of the processes of interaction in terms of classical mecahnics. Since the C. I. asserts that these concepts are inadequate means for describing the states of a system at micro level, we ought not, accordingly, retain the classical notions of wave, particle, position, momenta and such like, but should make them less specific. This leads to the conclusion that in the micro-world the question of the reality of what is not being observed ( because it *cannot* be observed; not simply that we are not observing it ) is meaningless. Since whether a " particle " behaves like a particle or a wave is dependent on the observation that we make of it, we can see that when no observation is being made it is meaningless to say whether the "particle" is a particle or a wave. Similarly,whether a micro-entity has a well-defined position or moments is again determined by the observation since in the quantum region " position " and " momenta " are not classical notions and micro-entities do not possess these properties in the classical sense. This leads to the conclusion that no statement ascribing any property to a micro-entity is true unless an empirical verification is actually carried out. This epistemological ( i.e. dealing with the conditions of human knowing ) assertion has been paraphresed by Mehlberg as the " principle of truth-indeterminacy of empirically unverified statements about micro-objects."[13]

As a consequence of complementarity and the uncertainty relations the probability of finding a particle in an appropriate place is given by the squared amplitude of the wave, when a position *measurement is made*. The obvious question, whether the system possesses the values of its physical attributes prior to the measurement or whether these are given to the system by the measurement itself, is answered by the C. I. in the form that micro-observables cannot be asserted to exist unless measured.

The C. I. extends this epistemological principle to ontological one, i.e. dealing with what there is. Heisenberg asserts that objective reality has evaporated. Physics has only to deal with observables. The concept of reality independent of observation has to be given up. Bohr, however, would maintain that this does not extend to the micro-observables. Here realism holds and the variables have sharp values irrespective of measurement.

The function, the probability function, is what defines, mathematically, the states of a system in relation to the measuring apparatus.[14] The system and the measuring apparatus cannot be visualised separately. This position of the C. I. has been brought out sharply because of the objection raised by Einstein, Podolsky and Rosen.[15] Einstein, Podolsky and Rosen suggested that the uncertainty is due to the interaction of the measuring apparatus with the observed phenomena and, therefore, in an hypothetical experiment, if it was possible to compute the position and momenta without this interference, uncertainty would vanish. Their argument is as follows. Let two systems, $S_1$ and $S_2$ interact with each other for a certain length of time. Let the states of this system be described by 1,2. Let the two systems now be separated spatially by a great distance so that they do not have any significant reciprocity. Now, if a measurement is made on $S_1$ the probability function corresponding to this ( 1 ) combined with the probability function of the whole system S (1,2), it would give entirely definite values to $p^2$ and $q^2$ of the system $S_2$. Einstein, Podolsky and Rosen, on the basis of this, suggested that either we say that it is not possible to make a measurement on a system without disturbing the combined system as a whole although they are widely separated, or else the assumption that the probability function gives the complete description of the physical system must be abandened. Bohr, dealing with this objection of Einstein, Podolsky and Rosen, argued as follows.[16] As soon as the measurement of $p^1$ is made in the system $S_1$ the interaction of the system with the measuring device would destroy any exact knowledge of $q^1$ and hence of $q^2$ ( $S_2$ ) as well.

Thus in the C. I. the measuring apparatus and the observed object are to be considered as an indivisible system. They are " glued together ", so to speak, by an indivisible quantum during the process of interaction. The quantum, belonging to both and yet indivisible, implies that the observing apparatus and the observed system cannot even conceptually be analysed into further parts.

Thus in no way can properties and qualities of the system under observation be described independently of those of the measuring device or the observing apparatus. To talk of the properties of a micro-object when it is not being observed is inconceivable in the C.I.. Since to talk of the properties of the micro-object when it is not being observed is " meaningless ", one must conclude that its only mode of existence is being observed.

The relational concept of the probability-function gives rise to a major difficulty. Where is the line to be drawn between the observing apparatus and the observed phenomena ?

The demarcation line between the observing apparatus and the observed phenomena is " to some extent arbitrary ".[17] In conformity with the Correspondence Principle, any inclusion of the observing device in the phenomena to be observed results in the study of a new more complex phenomena. This does not alter the situation regarding the results of the quantum theory so long as this new complex is in the microscopic domain which leaves the situation regarding quantum laws unalterable, because even this new, more complex, phenomenon has to interact with certain other measuring devices to make any sense in the quantum theory. If it thus becomes macroscopic then classical laws are applicable.

According to Heisenberg the demarcation or dividing line can be seen as follows :[18]

Schism in the investigation of atomic process—

| *Classical* | *Quantum* |
|---|---|
| Plain concepts of space and time | ..Wave function in multi-dimensional configuration-space which allows no comprehensible interpretation |
| Measuring apparatus | ..Representation by probability function |
| Inter-relation defined by classical laws | ..Inter-relation defined by Schrodinger's wave equation |

The effect of the means of observation on the observed body is conceived as disturbance, uncontrolled in the region of the dividing line and giving rise to the Uncertainty Relations and the statistical nature of the quantum laws. This serves as a " wonderful " method of linking up the classical and the quantum on either side of the dividing line where unambiguous formulations can be made. The dividing line is defined by the nature in classical and quantum domains. For this reason "there must, within certain limit, exist *complete freedom* in 'choosing' the position of the dividing line."[19]

The arbitrary choice of the dividing line and the relational character of the function give rise to the fact that the laws of micro-systems apply to macro-systems as well. Would, therefore, the unreality of the unobserved variables extend to the macro-domains also ? Within the C. I. this question is taken care of by the Correspondence Principle. According to this principle, for the phenomena in which Planck's constant can be considered negligible, the laws of quantum theory are approximately identical with the classical laws. This gives us the "happy" situation where the Uncertainty Relations do not assume serious proportions in the macroscopic domain.

The arbitrary nature of this macro-realism in the C. I. has been sharply posed in many cases. An interesting case is Schrodinger's Cat Paradox. Schrodinger imagined an isolated system consisting of an apparatus that contains a cat together with a device for electrocuting the cat. At a certain present time, an emitter emits a single photon directed towards a half-silvered mirror. If the photon is deflected then the cat will live; if the photon passes through the half-silvered mirror then the switch will be turned on and the cat will be electrocuted. The event of the photon passing through the half-silvered mirror is one whose quantum mechanical probability is exactly $\frac{1}{2}$. If this entire system is represented by a wave function then prior to the time at which the emitter emits the photon—say, 12 : 00—the wave that represents the state of the system will evolve in accordance with the classical limit theorems, that is to say, all macro-observables, including the ones that describe the behaviour of the cat, will retain "sharp values" "by themselves". When the photon is emitted, however, the effect of the half-silvered mirror will be to split the wave corresponding to the photon into two parts. Half of the wave will go through the half-silvered mirror and half will be reflected. From this point on the state of the system will be represented by a linear combination of two waves, one wave representing the system as it would be if the photon passes through the half-silvered mirror and the cat were electrocuted, and the other wave representing the state of the system as it would be if the photon were reflected and the cat were to live. Thus, if the system is not interfered with prior to 1 : 00 p.m., then we will predict that at 1 : 00 p.m., the system will be in a state that is a superposition of " live cat " and " dead cat ". We then have to say that the cat is *neither alive nor dead* at 1 : 00 p.m., unless someone comes and looks at it and that it is the act of looking that *throws the cat into a definite state.* This result of course, would be contrary to the macrophysical realism espoused by the C.I.. Schrodinger's Cat Paradox brings out the fact that the Correspondence Principle that " macro-observables retain sharp values at all times is not deduced from the foundations of quantum mechanics but is rather dragged in as an additional assumption."[20]

Such a situation which is not unusual in quantum mechanics raises the question of whether or not observation means "conscious" act of observation. Bohr has maintained, and most physicists have agreed with him, that the " subjective " or abritrary nature of the dividing line does not mean that the " uneality " present in the micro domain extends to the macro domain. In the macro domain, according to them, the macro-vaiiables retain sharp values independent of observation.

On the other hand a number of physicists, notably London and Hoitler, maintain that the act of " observation " means a " conscious " observation, i.e. the observer appears " in his full capacity as a conscious being."[21] As a physicist holding this view unambiguously phrases it, "..the laws of quantum mechanics itself cannot be formulated..without recourse to the concept of consciousness."[22]

To throw out the subjectivist interpretation from the C. I, Heisenberg says that the probability function is a mixture of objective and subjective elements. " It contains statements about possibilities or better tendencies, ( ' potentia ' in Aristotelian Philosophy ) and those statements are completely objective; they do not depend on any observer; and it contains statements about our knowledge of the system, which of course are subjective in so far as they may be different for different observers ".[23] According to Heisenberg " subjective " is not taken to refer to the psychology or consciousness of the observer, but to the measuring device, which is macroscopic and essentially linked with the microscopic. But it is subjective in the sense that the measuring device has been constructed by the observer and on this construction depends the type of " reality ", or the manifestation of it—whether particle or wave—, that we study. In other words, " what we observe is not nature in itself but nature exposed to our method of questioning."[24]

" The probability function does not allow a description of what happens between two observations. Any attempt to find such a description would lead to contradictions; this must mean that the term " happen " is restricted to observation."[25] This restriction can be the result either of the limitations of scientific development so far, or of the fact that nothing happens between observations, in which case the question is meaningless. The only consistent answer within the C. I. is the second, the positivist one, i.e. it is observationally and therefore conceptually a meaningless question. In true positivist spirit reality is observer or obeservation dependent.

Various implications follow. What we deal with are not the properties of micro-objects as such, but rather the relationships that hold amongst observable large-scale phenomena. Thus, science is no longer a study of nature in itself but is the study of our sense impressions—their structure, ordering, co-relation, and regulations.[26] This is sharply put by Philip Frank : " In the technological use of science we have to connect general laws with statements about sense impressions. Hence every conclusion drawn from physical laws can only be a statement about sense observations of physical facts."[27]

The success of quantum mechanics is due to the fact that its mathematical formalism gives correct predictions for observables. The function gives the probability for finding a definite physical magnitude in a definitely given interval. This probability is empirically determinable—it permits the description of the mean behaviour of a statistical aggregate of systems.

Quantum Mechanics answers properly put statistical questions. This has led the adherents of the C.I. to consider the sole purpose of science to be the making of reliable predictions of events as yet unknown. This attitude is expressed by Bohr in his arguments with Einstein, saying that there could be " no other way to deem logically consistent mathematical formalism as inadequate than by demonstrating the departure of its consequences from experience or by proving that its predictions did not exhaust the possibilities of observation..".[28] The positivist attitude to the function of science is apparent in the understanding "that the appropriate physical interpretation of symbolic quantum mechanical formalism amounts only to predictions, of determinate or statistical chaiacter."[29]

An assumption underlying the interpretation of the Copenhagen School is that the present day quantum mechanics is a rational summary of facts and that any further theory must also be so. The interpretation is taken to be a 'unique' interpretation, "Now, quantum theory eminently possesses this character of uniqueness; every feature of it has been forced upon us as the only way to avoid the ambiguities."[30]

This assumption is the basis of the assertion that the duality of particles and waves which arises due to the use of classical concepts cannot be overcome. The propounders of the C. I. repeatedly emphasize that our experience must be described in classical notions which are said to be either "intuitively given" or "inborn".[31] Any possibility of the search for a more complete conception is renounced "in principle".[32] Apart from the qualitative argument of Bohr for expressing all evidence in terms of classical concepts, there is Von Neumann's proof according to which any further theory of the microscopic domain which tries to get fuller descriptions of its phenomena in terms of "hidden variables", i.e. variables not known thus far, is ruled out.[33]

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NOTES

1. Bohr N.; *Einstein: Philosopher-Scientist* ed P. A. Schilpp, Discussion with Einstein p. 200.
2. Ibid p. 238.
3 Ibid p. 238.
4. Rosenfeld : *Observation and Interpretation* ed. S. Korner-Misunderstandings about the foundations of quantum theory, p. 42.
5. Bohr N.; *Atomic Theory and Description of Nature*, p. 5
6. Ibid p. 70, 110.
7. Rosenfeld; op. cit. p. 42.

8. Bohr N.; op. cit. p. 12.

9. Feyerabend P. K., *Frontiers of Science and Philosophy ed. R. G. Colodny*, Problems of Microphysics p. 196.

10. Rosenfeld; op. cit. p. 44.

11. Feyerabend P. K.; op. cit. p. 196 see f.n. 39.

12. Feyerabend's effort to show Bohr's materialist intentions has the following consequences :—

(1) Bohr strictly (or not so strictly) adhered to the scientific method and was himself reluctant to draw any hasty ontological inferences from formalism. He was fully aware of the approximate and pragmatic nature of quantum mechanics formalism.

(2) He used subjectivist terminology less frequently than Heisenberg and there are differences between him and Heisenberg on the acceptance of a pure positivist interpretation of Physics.

(3) He was aware of the limited applicability of the results of quantum mechanics, both in terms of the historical development of science and in terms of the domain of the applicability of such laws.

(4) He would not be averse as a " philosopher " to the discovery of new domains or contexts in which different laws might apply. This is indicated in Feyerabend's characterisation of Bohr's attempts as a return to Bohr.

13. Mehlberg H.; *Quantum Theory and Reality ed. Mario Bunge*. The problem of Physical Reality in Contemporary Science pp. 45–65.

14. Heisenberg holds the view that only such experimental situations can arise in nature as can be expressed in mathematical formalism. See his *Physics and Philosophy* p. 4 ; Michael Polanyi asserts that " it appears that the predominant principle that shaped modern physical theory was not the positivist programme, but the transition from a mechanical conception of reality to a mathematical conception of it, which sometimes coincided with the positivist programme for the purification of science ". (*British Jr. of Philosophy of Science 18 ( 1967 )* : Science and Reality pp. 177–198.)

Our attempt is to show that in the C.I. this mathematical transformation is not a case of occasional coincidence but is a consistent development along positivist lines.

15. Einstein, Podolsky & Rosen : *Phy. Rev.* 47 ( *1935* ), Can quantum-mechanical description of physical reality be considered complete ? pp. 777–783.

16. Bohr. N.; *Einstein : Philosopher–Scientist* Discussion with Einstein p. 232.

17. Heisenberg : *Physics and Philosophy*, p. 57.

18. Heisenberg : *Philosophical Problems of Nuclear Physics*. pp. 54–55.

19. Ibid.

20. Hilary Putnam : *Beyond the Edge of Certainty ed. Colodny*, A Philosopher looks at Quantum Mechanics p. 95.

21. Heitler W.; *Einstein : Philosopher-Scientist* The Departure from Classical Thought in Modern Physics p. 194.

22. Wigner E. P.; quoted by Popper, K : Quantum Mechanics without "The Observer" *Quantum Theory and Reality.*

23. Heisenberg : *Physics and Philosophy* p. 52.

24. Ibid.

25. Ibid p. 54.

26. '... in our description of nature the purpose is not to disclose the real essence of the phenomena, but only to track down, as far as it is possible, relations between the manifold aspects of our experience'.

N. Bohr; *Atomic Theory and the Description of Nature*, p. 18.

27. Philip Frank; *Science and Society ed. Vavoulis and Colver*; Philosophical Uses of Science p. 142.

28. Bohr, N.; op. cit.

29. Bohr. N.; op. cit. p. 238.

30. Rosenfold; op. cit.

31. Heisenberg; *Science and Society*; Plank's Discovery and Philosophical Problems in Nuclear Physics pp. 111–112.

32. '... in quantum mechanics we are not dealing with an arbitrary renunciation of a more detailed analysis of atomic phenomena, but with a recognition that such an analysis is in principle excluded :

N. Bohr; *Einstein : Philosopher-Scientist* p. 235.

33. In essence the proof consists in the derivation of two theorems, the first asserting that no ensemble of quantum mechanical systems is dispersion-free, and the second asserting that the ensembles of minimum dispersion are such that anyone of its finite sub-ensembles possesses the same properties as it itself.

Von Neumann; *Mathematical Foundations of Quantum Mechanics.* In this proof, unlike Bohr's argument, both the observed system and the observing device are described with the help of a function. The proof is based on taking certain results from quantum theory and its interpretation as final and then goes to prove that it is so.