THE KÖNIGSBERG INTERPRETATION OF QUANTUM MECHANICS?

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It is surely a truism that the science and philosophy of an age influence one another; and this century has been no exception: the rise of quantum theory in particular profoundly threatened the most promising and universally respected philosophic conception of the physical world articulated since the demise of the Aristotelian doctrines of nature. In so doing, this bold theory precipitated one of natural philosophy's most dramatic disputes, between two of the century's most distinguished physicists, Niels Bohr[1] and Albert Einstein.[2] Therein, Bohr adamantly contended that possible knowledge of physical reality was essentially circumscribed by extant quantum theory, while Einstein just as trenchantly argued that it was not. On the outcome of that important dialogue, the so-called "EPR" exchange, thus rested more than philosophical speculation: the future development of one of the two principal branches of contemporary physics was at stake.

But though its consequence has always been clear, the detailed structure of the dispute has proven difficult to divine: in the lapse of four decades since its publication, no convincing account of Bohr's contribution in particular to that dialogue has appeared.[3] Toward a modest mitigation of that unfortunate circumstance, then, I wish to argue in this essay that Bohr's reply, if cogent, must boldly presuppose that:

(B) We are condemned to conceive the physical world through the concepts of Newtonian and Maxwellian physics.

To achieve this end: (1) the EPR argument will first be reviewed to provide a criterion of adequacy for the interpretation of Bohr's counter; then (2) that reply will be critically assessed against this criterion to show that the rejoinder must, if cogent, assume B.

1. The EPR argument. The object of the EPR argument is to show that the quantum theory fails to describe "completely" certain quantum-mechanical events. Provided that it is possible to achieve such completeness, it would follow that the theory does not represent limita-

tions on human knowledge of physical reality, contrary to Bohr's assertions.

The argument begins by positing the existence of a theory-independent "physical reality" which a "complete" theory must in some sense mirror:[4]

> (C) Every element of physical reality must have a counterpart in the theory.

To determine whether the quantum theory in particular satisfies C, of course, a means of determining the "elements of reality" independently of the theory must be provided. This task, the argument maintains, can be accomplished by "an appeal to the results of experiments and measurements," and more specifically,

> (R) If without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.[5]

Using these criteria, respectively dubbed the "criterion of completeness" and the "criterion of reality," the argument then analyzes a hypothetical system K whose state is characterized by a wave function ψ. Now according to the quantum theory, there corresponds to each physically observable quantity A (such as position, momentum, and so forth) of K an operator, which for convenience will be designated by the same symbol as the physical quantity. If ψ is an eigenfunction of the operator A, that is, if

$$(1) \qquad \psi' \equiv A\psi = a\psi$$

where *a* is some number, then the physical quantity A has the value *a* with certainty whenever K is in the state given by ψ. Thus, if K is determined to be in ψ without disturbing that system, the criterion of reality, R, implies that there is an "element of reality" corresponding to A. If (1) does not hold, however, the quantum theory does not afford a means of determining a particular value of A; instead the theory assigns a probability less than unity to each value in an interval containing *a*. Under such circumstances the value of A can be determined, if at all, only by measurement. Measurement, however, in some sense "disturbs" K; more specifically, the value of the operator canonically conjugate to A is not determinable under the theory after measurement. To this case, then, the criterion of reality cannot be applied. The question thus naturally arises: after measurement, do the physical quantities corresponding to noncommuting (canonically conjugate) operators (a) have physical reality, or (b) not? If it could be shown that there are physical quantities which have simultaneous reality and which correspond to noncommuting operators, it would follow that (b) would be false and hence the quantum theory would fail to satisfy the criterion of completeness; the object of the argument at this stage, then, is to describe a system which falsifies (b).

To achieve this end, the argument considers a hypothetical pair of systems, denoted I and II, respectively, whose joint behaviour is characterized by a wave function Ψ . I and II are allowed to interact throughout a time interval [0,T]. If the states of I and II are known before T=0, Ψ allows computation of the state of the combined system I+II at any time after T, but does not afford a means of determining the states of the respective "component" systems (I and II) of this complex. Thus the states of the component systems can be determined, if at all, only by measurement. Now the quantum theory asserts that the measuring process in the complex is to be analyzed in the following way. If $a_1, a_2, a_3, \ldots$ are the eigenvalues of a physical quantity A of system I and $u_1(x_1), u_2(x_1), u_3(x_1), \ldots$ the corresponding eigenfunctions, where x_1 stands for the variables used to describe I, then Ψ is expressed as

$$(2) \qquad \Psi(x_1,x_2) = \sum_{n=1}^{\infty} \psi_n(x_2) u_n(x_1)$$

where x_2 stands for the variables used to describe the second system. If A is measured in system I and found to have the value a_k, the theory implies that after measurement, I is left in the state given by $u_k(x_1)$, and II is left in the state given by $\psi_k(x_2)$ with certainty. The set of functions $u_n(x_1)$ is determined by the choice of the physical quantity A. Thus if some other physical quantity B with eigenvalues $b_1, b_2, b_3, \ldots$ were chosen to be measured, then, on analogy with (2)

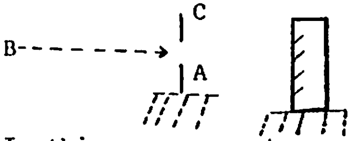
$$(3) \qquad \psi(x_1,x_2) = \sum_{n=1}^{\infty} \phi_s(x_2) v_s(x_1)$$

would obtain. If B is measured and found to have the value b_r, then the quantum theory analogously implies that after measurement system I is given the function $v_r(x_1)$ and II is assigned the function $\phi_r(x_2)$ with certainty. So depending on what physical quantity in I is measured, II is assigned two wave functions, $\psi_k(x_2)$ and $\phi_r(x_2)$ with certainty. Since measurement in I does not "disturb" II, the criterion of reality implies that $\psi_k(x_2)$ and $\phi_r(x_2)$ have simultaneous reality.[6]

In particular, then, suppose that the two wave functions $\psi_k(x_2)$, $\phi_r(x_2)$ are eigenfunctions of two noncommuting physical quantities P,Q, respectively.[7] The above remarks imply that by measuring system I the value of P or Q in system II can be predicted with certainty. And since by assumption I and II do not "interact" after T, II is not "disturbed" by measurement in I. Thus by the criterion of reality, both P and Q in system II have "simultaneous reality." Hence, two physical quantities corresponding to two noncommuting physical operators can have simultaneous reality, (b) above is false, and thus the quantum theory is incomplete.[8]

2. Bohr's EPR reply. It is clear that to overcome the EPR argument, it would suffice to impugn either the "criterion of completeness," C, or the "criterion of reality," R. Though this is in fact Bohr's aim, at first blush his reply appears to be without force against the paradox: the reply first notes the criterion of reality, then dogmatically proceeds to reject it.

Bohr begins by agreeing with EPR that knowledge of physical reality must come through the mediation of measurements. Further, he claims that the essential features of measurement in quantum mechanics [and hence, in EPR's system I+II] can be captured in two simple idealized experimental arrangements, each of which can be represented schematically by a variation of a diagram of the following general sort:



(I)

In this arrangement, a particle, say a photon or electron, is emitted at B, passes through a narrow slit A in C and strikes a target at D. The dotted line below C indicates that C may or may not be rigidly attached to the frame to which D is attached; this is determined by the parameter being measured. Suppose in particular the momentum of the particle were to be measured. For such a measurement the diaphragm C is allowed to move freely. Because C is free to move, there is an uncertainty Δq in the position of the slit A after measurement, Bohr claims; in particular, de Broglie's relation between momentum and wavelength implies that an uncertainty Δq of the position in the same direction as the momentum is related to an uncertainty Δp in the momentum of the particle by Heisenberg's relation, $\Delta p \Delta q \sim h \neq 0$, where h is Planck's constant. A similar analysis holds for measurement of position; in this case Bohr claims that C must share a rigid common support with D, and that an "uncontrollable" part of the momentum is thus allowed to pass into that support during measurement, rendering application of the conservation law of momentum to future states of the particle impossible. Because there are such "limitations" (or, in rather strained mechanical terminology, "influences," or "effects") between canonically conjugate quantities, one can see that there is a fatal ambiguity in EPR's criterion of reality occurring in the phrase "... without in any way disturbing a system ...," Bohr concludes. For even if there is no mechanical disturbance of the system when a measurement is performed on it, the state description of that system is nevertheless "limited," "affected," or "influenced" by measurement in a way which always respects the Heisenberg relations.[9]

Taken at face, these remarks constitute an unfortunately dogmatic rejection of the EPR argument. It is by no means clear, for example, why one should accept Bohr's assertions that (I) somehow exhausts the "possibilities of measurement" or that the Heisenberg relations circumscribe our possible knowledge of canonically conjugate parameters. For it might be argued that Δp and Δq merely represent information about the statistical distribution of the momenta and positions of very large collections of individual systems. On such a view, every member of such collectives has a definite position and momentum, or more generally, every state variable has a definite value. For these individual systems, then, Δp would be 0 and Δq would be 0. Thus "Heisenberg's relations" for the individual systems would become $\Delta p \ \Delta q \sim h \to 0$, which, by implying that $h \to 0$, contravenes Bohr's analysis.

If there is any force in this view, Bohr's claim that $h \not\to 0$ no matter what, seems poorly motivated. Lamentably, he never provides any substantive argumentation in the EPR reply or elsewhere for this crucial assertion. Even his unpublished letters and manuscripts offer only the vaguest hints concerning these matters;[10] as a result textual evidence radically underdetermines any account of his views. It might therefore be imagined (with some justice) that no interesting analysis of the EPR reply were possible. Yet however discouraging a prospect the dearth of such evidence may present, the results of the last section have provided a touchstone of adequacy for any interpretation of Bohr's rejoinder: in the absence of evidence to the contrary, sympathy demands that any explication which fails to render the EPR reply cogent against the EPR argument must be rejected. What follows, then, must be regarded as an attempt to conjecture the details of the reply within the constraints of this criterion.

To establish the cogency of Bohr's claim that for classical physics at least, it is sufficient to show that

(A) If $h \rightarrow 0$, some well-accepted law of classical physics fails.

Toward this end, then, it will now be argued that if $h \rightarrow 0$, as EPR propose, then given Newtonian mechanics and Maxwelliam electrodynamics, the field of every blackbody enclosure must have infinite energy density; hence those whose fields contain a finite amount of energy must violate the first law of thermodynamics. Throughout this argument, it is assumed that the radiative processes of blackbodies may be treated as the result of the energetic behaviour of a large number of oscillators. Now it can be shown from Newtonian mechanics that the average energy, $\bar{\varepsilon}$, of each such oscillator is

(4) $\bar{\varepsilon} = h\nu/(e^{h\nu/kT}-1)$

where <u>h</u> is Planck's constant, <u>k</u> is Boltzmann's constant, and ν is the frequency and T the absolute temperature of the oscillator, respectively. A power series approximation of the term $e^{h\nu/kT}$ yields

(5) $e^{h\nu/kT} = 1+h\nu/kT=h^2\nu^2/2k^2T^2+\cdots$

Assuming EPR's claim that $h \rightarrow 0$, we have, to first order in <u>h</u> from (5) that

(6) $e^{h\nu/kT}-1 = h\nu/kT$

From (4) and (6) it then follows that

(7) $\bar{\varepsilon} = kT$

Furthermore, it can be shown from Maxwelliam electrodynamics that the number dn of modes of vibration per unit volume with wavelengths in a range $d\lambda$ in a blackbody enclosure is

(8) $dn = 8\pi \, d\lambda / \lambda^4$

The radiant energy per unit volume in the wavelength range $d\lambda$, $\psi_\lambda \, d\lambda$ where ψ_λ is the energy at wavelength λ is thus kTdn, or by (8), $8\pi kTd\lambda / \lambda^4$. This implies that

(9) $\psi_\lambda = 8\pi kT\lambda^{-4}$

Two features of (9) now command our attention. First of all, at short wavelengths (9) diverges drastically from experimentally observed values.[11] But worse is true, for since there is no lower positive limit to the magnitude of wavelengths in the field, the energy density in the field is $\int_\lambda \psi_\lambda \, d\lambda = \int_\lambda 8\pi kT \lambda^{-4} d\lambda$, which goes to infinity as λ goes to zero.

Thus, if there is some classical theory in which $h \to 0$, it follows that the field of every blackbody enclosure must have infinite energy density. This implies that the fields of those blackbodies which do not contain infinite energy must violate the first law of thermodynamics. Consistency therefore demands that either the claim $h \to 0$ (alleged by EPR to follow from the criterion of completeness), or some claim of Newtonian mechanics or Maxwellian electrodynamics be abandoned. Thus, Bohr's assumption that EPR's criterion of completeness is intimately wed to the denial of a fundamental feature of classical physics (A) is sound.

Yet the argument has not shown that there is no theory in which $h \to o$ obtains for all systems; for by fiat a non-classical theory in which that relation held could be constructed. More generally, the argument fails to establish that there is no cognitively significant theory in which all state variables can in principle assume arbitrarily precise values. Thus Bohr's argument against the criterion of completeness is cogent only if in some way it can be shown that non-classical physical theories fail to provide insight into physical reality. This is the burden Bohr hopes B will carry:

> (B) We are condemned to conceive the physical world through the concepts of Newtonian and Maxwellian physics.

Now to require B to play this role is implicitly to determine its philosophic status, though it is by no means apparent just what that status should be. Since Bohr provides few, if any, clues to its nature, B has been plausibly taken as: a consequence of the peculiarities of measuring insturments;[12] a consequence of certain features of human habit formation;[13] and a claim about necessary conditions on human cognition or language. Though the diversity of this field of interpretations can hardly fail to discourage even the most admiring disciple, the EPR argument once again supplies at least a touchstone of adequacy for any such interpretation: in the absence of evidence to the contrary, sympathy demands that any explication must at least render the role B plays in Bohr's reply cogent against EPR's proposals. Accordingly, these initially plausible characterizations of B will now be examined in order of their ability to approximate the status B must have to buttress the EPR reply.

The "measurement" interpretation. It has been argued by several authors[14] that B somehow derives from the nature of laws peculiar to the description of measuring instruments. More particularly, it is asserted that B follows from two other claims, one about the class of meaningful statements, and the other about the theory in which measurements must be described:

(S1) The only meaningful statements which can be made about the microscopic structure of matter must be limited to the outcomes of measurements on atomic matter that are made by macroscopic measuring devices.

(S2) The macroscopic measuring apparatus must obey the laws of "classical" physics.

From this it follows that the description of physical phenomena is possible only through the classical scheme (B).

While some physicists and philosophers in the post-Bohr "Copenhagen" tradition may defend a philosophy of quantum mechanics characterized by S1-S2, this interpretation nonetheless drastically misrepresents Bohr's intellectual inclinations, it will now be argued, because crucial details of the characterization cannot be consistently formulated, and furthermore, the view implies the impossibility of EPR-type experiments.

In particular, S1 is composed of at least two distinct claims:

(S1') The only measurements which can be made must be made by macroscopic measuring devices.

(S1") The only meaningful statements which can be made about the microscopic structure and behaviour of matter must be limited to descriptions of the outcomes of measurements.

Now S1' and S1" are jointly inconsistent. For at the least they presume a clear and fast distinction between "macroscopic-" (classical) and "microscopic-" (quantum) scale events. If such a distinction could be drawn, it would identify a small region of space, say, a sphere of diameter D, demarcating the respective kinds of events. Events occurring in spatial regions with diameters smaller than D would be assumed to have "quantum" behaviour: events requiring regions of diameter equal to or larger than D would be taken to obey "classical" laws. Now in the measuring process some part of the measuring instrument must be taken to interact with the system measured. And, in order for interaction to occur, some part of the measuring device must lie within the ball of diameter D. It must therefore be both meaningful and not meaningful, by S1", to describe the measuring apparatus, for parts of it, by the above analysis, are respectively elements of quantum and classical systems. Thus the distinction presumed by S1 cannot be consistently formulated.

Yet even if the "microscopic-macroscopic" distinction did not render the description of measuring instruments inconsistent, it would face still another difficulty. For any given value of D, an EPR-like experiment can always be constructed so that the quantum systems I and II are separated by a distance greater than D. (For example, experiments have been performed in which the separation of systems I and II is on the order of 1 meter,[15] and surely any reasonable value of D would be several orders of magnitude smaller than this.) By reasoning analogous to the above, then, it would be both meaningful and not meaningful to describe such events.

The "predicability" interpretation. The failure of the "measurement" interpretation discloses at least that any explication of B which tries to capture the criterion of meaning embodied in B by distinguishing meaningful from meaningless statements according to the spatial loci containing the events to which they refer threatens to deprive Bohr's account of consistency. This difficulty could be mitigated, it seems, by relaxing the constraints placed on the class of admissible statements. The next approximation of B to be examined does just this: according to this view, we are constrained to describe the "outcomes of experiments" solely in classical terms. From this it is alleged to follow that every description of physical reality must be cast in classical terms. Unless some further constraints are placed on the class of admissible statements, however, $h \to 0$ may be admitted, thus contravening A. To accomodate Bohr's interpretation of the Heisenberg relations in the classical scheme, then, this characterization holds that $\Delta p \, \Delta q \sim h$ is to be regarded as reflecting limitations on the "predicability" of values to canonically conjugate state variables. In general, a predicate "is *a*" is predicable of a parameter A_K $(1 \leq k \leq n)$, where $(A_1, \bar{A}_2, A_3, \ldots, A_n)$ is an ordered n-tuple of mutually canonically conjugate state variables in a system S, if and only if in S a parameter B from which, together with the wave equation and initial conditions, the value of A_j $(j \neq k, 1 \leq j \leq n)$ can be inferred, has not or is not being measured.[16]

Whatever its shortcomings, the "predicability" interpretation is a better approximation of B than the "measurement" interpretation. For the explication provides a consistent and plausible criterion for the perplexing problem of assigning values to canonically conjugate state variables. In spite of its attractions, the characterization is flawed. For the explication fatally divorces the interpretation of Heisenberg's relations from thesis B: even if we were constrained to employ only classical concepts in the description of experimental outcomes, nothing would thereby prohibit invoking non-classical notions to interpret theoretically these outcomes. In particular, nothing in the predicability interpretation of B prohibits invoking EPR's claim that there is a (non-classical) theory in which $h \rightarrow 0$; thus the explication divests the EPR reply of cogency.

But though the "predicability" interpretation, as formulated, cannot invest B with the cogency desired, it might be conjectured that if the explication were amended to hold that only descriptions of the outcomes of experiments could be admitted as meaningful statements about physical reality, it would then follow that all meaningful statements about physical reality must be cast in classical terms (B). In spite of its promise, however, this amended version of the "predicability" explication is still problematic. For if the term "experimental" in that characterization is not redundant, the explication must implicitly distinguish two mutually exclusive, non-empty classes of statements as "non-experimental" and "experimental," respectively. And, whatever its particulars, such a distinction would identify as "experimental" physical events P_i occurring during time intervals Ip_i contained in a time interval $[t_m \pm k]$, where k is some constant and t_m is the nearest point of the time intervals during which the nearest measurement or experiment capable of investing descriptions of P_i with cognitive significance occurs; events occurring wholly at times outside this interval would be characterized as "non-experimental." Now for any given value of k, an EPR-like experiment could in principle be constructed so that the time it took a signal or "effect" to travel from system I to system II would be greater than 2k; thus by performing a measurement or experiment on I, we would be forced by such a criterion to say that since such "effects" occurred during intervals disjoint from $[t_m \pm k]$, it would be meaningless to speak of the "effects" of measurement in system I on system II. And, if it were meaningless to speak of such effects, it could not be said that measurement on I "affected" II, and hence EPR's application of the criterion of reality to system K would be justified. This would imply that the physical quantities corresponding to noncommuting parameters could have simultaneous physical reality, and thus Bohr's analysis would be simply without force. Accordingly, even if amended, the predicability interpretation cannot entrench B in the manner desired.

The "habit" interpretation. The failure of the "predicability" and "measurement" interpretations to invest B with the cogency desired show that an adequate characterization of that problematic thesis should not attempt to found the implicit criterion of meaning in B on spatial or temporal loci. For in a manner analogous to the objection raised against the "measurement" interpretation, any criterion of meaning demarcating meaningful from meaningless statements on the basis of the spatial loci of events or properties referred to in those statements could be impugned by choosing the separation of systems I and II to be greater than the diameter of the ball demarcating the respective loci; similarly, in a manner analogous to the objection raised against the "predicability" interpretation, any criterion of meaning investing or divesting a given description of an event with cognitive significance according to a temporal locus [$t_m \pm k$] could be rendered inadequate by separating systems I and II by a distance appropriately smaller or larger than 2kc, where c is the speed of light. Now if there is any characterisitic which all physical properties or processsess possess, it is that they occur in spatial or temporal loci. Thus a successful explication of the criterion of meaning contained in B could not demarcate meaningful from meaningless statements on the basis of physical properties or processes. It might therefore be conjectured that such a criterion could be explicated on the basis of properties of language or cognition. The next characterization of B to be examined takes just this tack: according to it, the criterion of meaning in B derives from certain features of human cognitive habit formation; more particularly, the view holds that we tend to use just those naive concepts suggested by observation and experience. Physical objects, for example, are taken to move continuously through space, possess inertia, resist penetration, and so forth. Physical theory, the view further maintains, non-ampliatively abstracts generalizations from this observational data, and over time the conception of things thus acquired becomes so entrenched that we become incapable of conceiving outside it. Now as a matter of historical fact, the view asserts, the classical framework in particular has thus atrophied our power to conceive in novel ways; hence all understanding of physical phenomena is impossible except through the classical scheme.[17]

In spite of rendering the criterion of meaning embodied in B sufficiently universal to capture those

EPR-type experiments on which the "measurement" and "predicability" interpretations foundered, the "habit" interpretation is still not capable of investing B with the force desired. For nothing in that explication implies that our conception or experience must be through the classical mode in particular; presumably some other "universal" conceptual scheme, such as the Aristotelian doctrines of nature, would have worked as well to atrophy our concept acquisition power. And, more specifically, the "habit" interpretation does not forbid that we could entrench a "universal" theory in which $h \to 0$, a consequence argued above to be tantamount to accepting the criterion of completeness. On the whole, then, the promotion of B as a consequence of human habit formation cannot invest B with the cogency desired.

The "transcendental" interpretation. The failure of the "habit" interpretation discloses that any successful characterization of B must capture a necessity peculiar to the classical mode of experiencing: if the EPR reply is cogent, B must be taken to imply that it is in principle impossible to conceive physical reality except through the classical mode. For if it is even possible that physical reality can be conceived through non-classical concepts, then the conjecture that there is a cognitively significant theory in which all state variables may assume arbitrarily precise values held forth by the criterion of completeness is sustained and the EPR reply correspondingly emasculated.

To avoid these problems, then, an adequate explication of B must read that infamous thesis as a claim about necessary conditions on language or cognition. Now it might be plausibly doubted that even this characterization could invest B with the cogency desired. In particular, it might be argued that claims about necessary conditions on human cognition or language are merely empirical, though perhaps very general, and thus, that the EPR reply rests on an extremely implausible, if not empirically false thesis.

But however persuasive such reasoning may appear, the difficulty it raises can be avoided, I now wish to argue, for any criterion of "empiricality" which satisfies at least the following two conditions, and which admits claims about necessary conditions on human cognition or language as empirical, must also demand that such claims are contradictions:

(A1) If a sentence S is empirical, then there must be a set of cognizable or describable experiences on the basis of which we would reject S;

(A2) If a sentence S is empirical, those experiences under which we would reject S must be cognizable or describable whether S is true or false.

By "reject" in the above I merely mean "cease to hold." I do not require that there must be a set of experiences descriptions of which when conjoined with S (and perhaps some auxiliary sentences) yield a contradiction. Indeed a weaker pair of necessary conditions for empiricality is difficult to imagine.

That A1 and A2 are criteria we would wish to maintain can be seen from the following. First of all, if a criterion of empiricality does not satisfy A1, then that criterion would have to admit as empirical claims like "Unicorns propagate prolifically." But manifestly, sentences such as these are recognized as non-empirical. Secondly, if a criterion of empiricality did not satisfy A2, it would admit as empirical a sentence K, the describability or cognizability of whose disconfirming experiences depended on whether K was true or false. The describability or cognizability of experiences on the basis of which we would reject K would then imply the truth or falsity of K. Then the truth or falsity of K could be determined without appeal to experience. But that every empirical claim must appeal somehow to experience is manifest.

Now if a sentence S is empirical, then experiences on the basis of which we would reject S, must be describable or cognizable without implying the falsity of S, by A2. For if the mere describability or cognizability of experiences E on the basis of which we would reject a sentence S implied that S is false, then it would be the case, that S would be false no matter what E was. There is only one kind of expression of a consistent and complete language L which is false, no matter what, namely the contradictions of L. So a criterion of empiricality which would admit as empirical a sentence S such that the mere describability or cognizability of experiences under which we would reject S implied the falsity of S, would demand, necessarily, that S is a contradiction.

Now to suppose that an experience on the basis of which we would reject B in particular is even describable or cognizable is to suppose that B is false. For such an experience must be describable or cognizable if we assume that B is empirical, by A1. Furthermore, by A2, if B is empirical, then this experience must be describable or cognizable, even if B is false. But B, it will be recalled, is a claim about necessary conditions for the possibility of cognition or expression. In order for an experience on the basis of which we would reject B to be describable or cognizable even when B is false, therefore, B must be false. For to say that such an experience under which we would reject B is describable or cognizable when B is false is to say that the classical concepts are not required for the describability or cognizability of experience. Thus B is false, if the experiences under which we would reject B is merely describable or cognizable. And by the above argument, a criterion that satisfies A1-A2 and which admits B as empirical, requires that B must be a contradiction.

Hence, if the EPR reply is to be regarded as cogent B should be taken as non-empirical claim about necessary conditions on human conception or expression. This characterization, at last, is capable of conditionally investing the EPR reply with cogency. For if it is in principle impossible to conceive or describe the physical world except through the classical concepts, then Bohr's arguments against EPR's criteria of completeness and reality are quite forceful. In particular, if we could conceive or describe the world only through the concepts of Newtonian and Maxwellian physics (B), then the criterion of completeness, by implying that there is a cognitively significant non-classical theory, would just be false. And since this implies that the Heisenberg relations would represent an essential limitation on the simultaneous determination of conjugate parameters, the only interpretation of the criterion of reality capable of sustaining the EPR argument would also be false.

I have tried to argue, then, that if the EPR reply is cogent, it must presume B as a non-empirical claim about necessary conditions on human cognition or language. Whether B possesses any merit in its own right, is of course a problem well beyond the scope of this essay. But, if I may be permitted a parting speculation, one can hardly resist noting the strikingly neo-Kantian[18] flavor of Bohr's bold conjecture; perhaps the intrepid soul who may probe beyond these beginnings shall discover this strange child of physics, though fostered in København, was orphaned in Königsberg.

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NOTES

[1] Niels Bohr, "Can quantum mechanical description of physical reality be considered complete?" *Physical Review* 46(1935): 696-702.

[2] Albert Einstein, B. Podolsky, and N. Rosen, "Can quantum mechanical description of physical reality be considered complete?" *Physical Review* 47(1935): 777-780.

[3] Of course there has been no shortage of claimants to the title of its exposition. For example, see D. Nilson, *Bibliography: History and Philosophy of Quantum Physics*, Indiana University, 1973, manuscript, entry numbers 98, 100, 101, 106, 108-128, 192, 194, 196, 203, 205-207.

[4] Einstein, "Can ...?," p. 777.

[5] *Ibid.*

[6] *Ibid.* pp. 778-779.

[7] This claim must be argued, and EPR in fact do. But since the argument is rather technical and no philosophical issue relevant to this essay turns on it, details were omitted.

[8] Einstein, "Can ...?," p. 780.

[9] Bohr, "Can ...?," pp. 697-702.

[10] Films BSC 1-8, Bohr MSS 1-10, and Bohr MSS 10 Supplement together with miscellaneous uncatalogued scientific and personal papers by Bohr. I wish to thank the Trustees of the American Philosophical Society Library and Bohr's heirs for making these archives available to me.

[11] Lummer and Pringsheim, *Verhandlungen deutscher physikalischen Gesellschaft* 1 (1899): 23, 215; 2(1900): 163.

[12] Mendel Sachs, "Positivism, realism, and existentialism in Mach's influence on contemporary physics," *Philosophy and Phenomenological Research* 30(1970): 403-420.

[13] Paul Feyerabend, "Problems of microphysics," in Frontiers of Science and Philosophy, ed. by R. Colodny, University of Pittsburgh Press, Pittsburgh, 1962, pp. 230-231.

[14] See note 12 and also Phillip Frank, Foundations of physics," in International Encyclopedia of Unified Science, ed. by O.Neurath, R. Carnap, and C. Morris, University of Chicago Press, Chicago, 1955, pp. 475-476.

[15] H. Langhoff, "Die Linearpolarization der Verlichtungsstrahlung von Positronen," Zeitschrift für Physik 160(1960): 186-193; C. S. Wu and I. Shaknov, "The angular correlation of scattered annihilation radiation," Physical Review 77(1950): 136.

[16] Clifford Hooker, "The nature of quantum-mechanical reality: Einstein vs. Bohr," in Paradigms and Paradoxes, ed. by R. Colodny, University of Pittsburgh Press, Pittsburgh, 1972, p. 134.

[17] Feyerabend, "Problems ...," pp. 230-231.

[18] Perhaps something akin to the argument in Kant's Metaphysical Foundations of Natural Science would provide clues to the nature of an adequate argument for B.