BOĞAZİÇİ ÜNİVERSİTESİ
DERGİSİ

Beşeri Bilimler – Humanities Vols. 8-9 – 1980-1981

EPISTEMIC DETERMINISM IN QUANTUM THEORY*

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ABSTRACT

It is shown that, for a theory which is in principle epistemically deterministic, due to physical interactions in the process of measurement an assumption of an epistemic discontinuity in the description which the theory gives, reduces the objective state of affairs which the description constitutes to subjective compartments with epistemic cuts in between. It is argued that, quantum mechanics, although ontically and causally deterministic, constitutes a theory which is epistemically indeterministic in the above mentioned sense. Based on the particular model of prediction which obtains for quantum mechanics, it is claimed that the epistemic indeterminacy in quantum theory, although quantum mechanics is verified and corroborated by nature, cannot be ascribed to nature as an ultimate principle.

J.M. Jauch, in a paper titled "Determinism in Classical and Quantal Physics," explicates the notions of epistemic, causal, and ontic determinism as follows: "The first concerns statements such as: From the knowledge of the present state of a physical system I can deduce some properties of a physical state. The second affirms that the state of the present determines that of the future (and the past) by a universal process law. The third merely affirms existence of the world in the future from that of the present."(1)

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* This paper was presented to the Department of History and Philosophy of Science at the University of Pittsburgh in a colloquium on 2 March, 1980.

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The knowledge of any state of a physical system, with regard to CPM (classical particle mechanics) can be stated by means of a universal propositional function with the following components:

i. a physical object,
ii. physical quantities by means of which the state of the object can be determined, and
iii. numerical values of these physical quantities.

Such a universal propositional function can be formulated as follows:

the value of quantitiy f pertaining to
object Σ in state M at time t is α

Or in short:

$$H_t(\Sigma, f, \alpha) \qquad \ldots (1)$$

The universal propositional function given by (1) does not characterize any definite state of a particular physical object, but specifies what is necessary for such a characterization.(2)

The knowledge of a particular object in a definite state can be given by the following propositional function:

the value of quantity f pertaining to
object Σ in a definite state M at
time t is α_o

Or in short:

$$h_{Mt}(f, \alpha_o) \qquad \ldots (2)$$

Propositional functions of the kind $h_{Mt}(f, \alpha_o)$ contain factual knowledge. Whenever α_o is calculated by means of the mathematical machinary of CPM, then it will be said that $h_{Mt}(f, \alpha_o)$ contains theoretical factual knowledge. If, on the other hand, α_o is determined by means of observations, then $h_{Mt}(f, \alpha_o)$ carries empirical factual knowledge. To differentiate the latter from the first, the superscript e will be used for the latter one:

$$h^{e}_{MT}(f, \alpha_o) \qquad \ldots (3)$$

By means of the factual statements of type (3), the formal process of prediction (or, retrodiction) in CPM can be modelled by either of the following:

$$h_{Mt}(f, \alpha_o) \longrightarrow \boxed{\text{MM}} \longrightarrow h_{M(t \pm \Delta)}(f, \beta_o) \qquad \ldots (4)$$

$$h^{e}_{Mt}(f, \alpha_o) \longrightarrow \boxed{\text{MM}} \longrightarrow h_{M(t \pm \Delta)}(f, \beta_o) \qquad \ldots (5)$$

where MM denotes the mathematical machinary of the theory, i.e., CPM, in *which, and by means of which the theoretical and empirical factual statements* are obtained.

The following example will clarify the points which have been considered so far:

> Given CPM, let the equations of motion be determined by the following partial differential equations:
>
> $$\dot{p}_k = -\partial H / \partial q_k \text{ and } \dot{q}_k = \partial H / \partial p_k$$
>
> where the Hamiltonian function H gives the total energy, and is a function of momentum p and position q.

Then, with respect to this particular case, a theoretical factual statement has the form:

$$h_{Mt}(\,(p_k,q_k)\,,(\alpha_{ok}\,,\beta_{ok})\,) \qquad \ldots (6)$$

Prediction in CPM; or in other words derivation of the knowledge of some future state from the given theoretical factual statement could be written as follows:

$$h_{Mt}((p_k,q_k),(\alpha_{ok},\beta_{ok})) - \boxed{\begin{array}{l}\dot{p}_k = -\,\partial H/\partial q_k \\[1em] \dot{q}_k = \;\;\partial H/\partial p_k\end{array}} \rightarrow h_{M(t+\Delta)}((p_k,q_k),(\delta_{ok},\gamma_{ok})) \; (7)$$

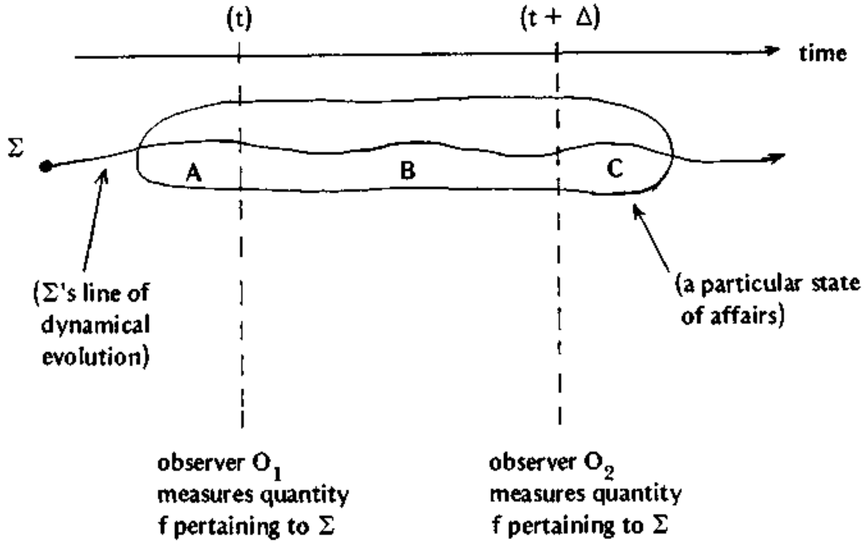
To obtain an empirical factual statement, the values α_{ok} and β_{ok} have to be determined experimentally. An experimental determination of these values amounts to the observation of the dynamical effects of the measured object on the measuring apparatus. Due to the dynamical effects of the measuring apparatus on the measured object, the object is disturbed as well. However, since in principle the disturbing effects of the measurement upon the object can be analyzed and calculated, the model of prediction given by (7) need not to be revised when the antecedent carries empirical factual knowledge.

$$h^{e}_{Mt}(\,(p_k,q_k),(\alpha_{ok},\beta_{ok})\,) - \boxed{\begin{array}{l}\dot{p}_k = -\partial H/\partial q_k \\[1em] \dot{q}_k = \;\partial H/\partial p_k\end{array}} \rightarrow h_{M(t+\Delta)}(\,(p_k,q_k),(\delta_{ok},\gamma_{ok})\,) \quad (8)$$

Since the knowledge of the future or past states can be inferred from that of the present one, CPM constitutes an epistemically deterministic theory of mechanics. This happens to be so because the factual statements CPM contains constitute a reality which is objective in an epistemic sense. It should be noted that the term objective reality is being used within the present paper in a weak epistemic sense without any ontological and metaphysical claims.

If, on the other hand, a state of affairs is reduced to subjective compartments with epistemic discontiuities in between, independent of whether the theory is causally and ontically deterministic, the theory cannot provide an overall picture which is epistemically deterministic.

To clarify this last point, let us consider the following thought experiment:



Picture 1.

By measuring the quantity f pertaining to Σ at time t, the observer O_1 obtains the following empirical knowledge:

$$h^{e1}_{Mt}(f, \alpha_{o1}) \qquad \ldots (9)$$

And the observer O_2, by measuring the quantity f pertaining to at time $(t + \Delta)$ obtains the empirical knowledge:

$$h^{e2}_{M(t+\Delta)}(f, \alpha_{o2}) \qquad \ldots (10)$$

From the empirical knowledge expressed by (9), O_1 can deduce the following predictions (or, retrodictions):

$$h^{1}_{M(t-\epsilon)} \longrightarrow \boxed{} \longrightarrow h^{e1}_{Mt}, \text{ where } t-\epsilon < t \qquad \ldots (11)$$

$$h^{e1}_{Mt} \longrightarrow \boxed{} \longrightarrow h^{1}_{M(t+\epsilon)}, \text{ where } t < t+\epsilon < t+\Delta \qquad \ldots (12)$$

$$h^{e1}_{Mt} \longrightarrow \boxed{} \longrightarrow h^{1}_{M(t+\Delta+\epsilon)}, \text{ where } t < t + \Delta + \epsilon \quad \ldots (13)$$

Similarly, O_2 can deduce the following:

$$h^{e2}_{M(t+\Delta)} \longrightarrow \boxed{} \longrightarrow h^{2}_{M(t+\Delta+\epsilon)}, \text{ where } t + \Delta + \epsilon > t + \Delta \quad \ldots (14)$$

$$h^{2}_{M(t+\epsilon)} \longrightarrow \boxed{} \longrightarrow h^{e2}_{M(t+\Delta)}, \text{ where } t < t + \epsilon < t + \Delta \quad \ldots (15)$$

$$h^{2}_{M(t-\epsilon)} \longrightarrow \boxed{} \longrightarrow h^{e2}_{M(t+\Delta)}, \text{ where } t - \epsilon < t \quad \ldots (16)$$

Assuming that there is an epistemic discontinuity between the observers O_1 and O_2, as a consequence of which neither of them knows in what magnitude the other had disturbed Σ, the following facts could be claimed for the regions A, B, and C of the thought experiment described by picture 1:

For region A : $h^{1}_{M(t-\epsilon)} \neq h^{2}_{M(t-\epsilon)}$ ... (17)

For region B : $h^{1}_{M(t+\epsilon)} = h^{2}_{M(t+\epsilon)}$ ... (18)

For region C : $h^{1}_{M(t+\Delta+\epsilon)} \neq h^{2}_{(t+\Delta+\epsilon)}$ ... (19)

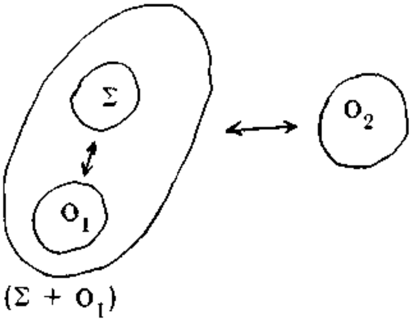
The following is an immediate consequence of (17), (18), and (19): Region B of the state of affairs is objective with respect to both of the observers. Whereas A is not objective with respect to O_2, and C is not objective with respect to O_1.

When a particular region of the state of affairs given by picture 1 is not objective with respect to an observer, then the factual statements inferred by that observer himself cannot possibly describe the state of affairs in that particular region. Such factual statements most likely are to be false a priori.

Hence, it follows that a non-objective compartment, i.e., non-objective with respect to an observer, of a state of affairs cannot be described by a theory which is epistemically deterministic, although the same theory can be causally and ontically determistic. It is being assumed that causal and ontic determinacy are compatible with epistemic indeterminacy with respect to a theory.

Objectivity, in the sense which is being used in the present paper, is a necessary requirement for epistemic determinism. This old, obvious, and perhaps apparently trivial point when thought of in a theoretical context other then CPM, might bring in some philosophical insights to the question of the deterministic status of that theory, namely of quantum theory.

Let us consider the following case with regard to CPM:



Picture 2.

Let us assume that the observer O_1 interacts with object and the observer O_2 interacts with $(\Sigma + O_1)$. Given that the following theoretical factual statements:

$$h^{1}_{\Sigma M t} \qquad \ldots (20)$$

$$h^{2}_{(\Sigma + O_1) M t} \qquad \ldots (21)$$

obtain for the observers O_1 and O_2 respectively, these observers can deduce the following from (20) and (21):

$$h^{1}_{\Sigma Mt} \relbar\joinrel\relbar\boxed{}\relbar\joinrel\longrightarrow h^{1}_{\Sigma M(t+\Delta)} \qquad \ldots (22)$$

$$h^{2}_{(\Sigma+o_1)Mt} \relbar\joinrel\relbar\boxed{}\relbar\joinrel\longrightarrow h^{2}_{(\Sigma+o_1)M(t+\Delta)} \qquad \ldots (23)$$

$$h^{2}_{(\Sigma+o_1)Mt} \relbar\joinrel\relbar\boxed{}\relbar\joinrel\longrightarrow h^{2}_{\Sigma M(t+\Delta)} \qquad \ldots (24)$$

So that the following is the case:

$$h^{1}_{\Sigma M(t+\Delta)} = h^{2}_{\Sigma M(t+\Delta)} \qquad \ldots (25)$$

So far, there is no epistemic discontinuity. Assuming that the observer O_1 measures the quantity f pertaining to Σ at time t_m and obtains the empirical knowledge given by:

$$h^{e1}_{\Sigma Mt_m} \qquad \ldots (26)$$

the observers could deduce the following predictions:

$$h^{e1}_{\Sigma Mt_m} \relbar\joinrel\relbar\boxed{}\relbar\joinrel\longrightarrow h^{1}_{\Sigma M(t_m+\Delta)} \qquad \ldots (27)$$

$$h^{2}_{(\Sigma+o_1)Mt_m} \relbar\joinrel\relbar\boxed{}\relbar\joinrel\longrightarrow h^{2}_{(\Sigma+o_1)M(t+\Delta)} \qquad \ldots (28)$$

$$h^{2}_{(\Sigma+o_1)Mt_m} \relbar\joinrel\relbar\boxed{}\relbar\joinrel\longrightarrow h^{2}_{\Sigma M(t_m+\Delta)} \qquad \ldots (29)$$

So that:

$$h^{1}_{\Sigma M(t_m+\Delta)} \neq h^{2}_{\Sigma M(t_m+\Delta)} \qquad \ldots (30)$$

That is, as a result of the measurement performed upon Σ, there is an epistemic discontinuity between the observers O_1 and O_2.

The epistemic indeterminacy in this case is a consequence of the epistemic discontinuity which prevents O_2 from determining the dynamical terms in what magnitude O_1 had affected Σ. However, since in CPM such an epistemic discontinuity in principle need not to be assumed, by making suitable corrections on the values of the measured quantities, the observer O_2, by means of CPM, could obtain the theoretical factual statement which is same as the empirical factual statement of O_1. That is, by theoretical manipulations:

$$h^1_{\Sigma M(t_m + \Delta)} = h^2_{\Sigma M(t_m + \Delta)} \qquad \ldots (31)$$

could be obtained.

However, there are cases where, in principle, the magnitude of the effects of the interaction due to measurement of the object cannot be analyzed and known. Such a case arises when Σ is taken as a micro-system so that its dynamics, instead of CPM, has to be described by QM (quantum mechanics).

Let us assume that the observer O_1 describes the state of Σ by $\Psi^1_{\Sigma t}$ and O_2 describes the state of $(\Sigma + O_1)$ by $\Psi^2_{(\Sigma + O_1)t}$, where Ψ is the usual wave function of the Schrödinger formulation of non-relativistic quantum theory.

Then, O_1 and O_2 could obtain the following predictions:

$$\Psi^1_{\Sigma t} \xrightarrow{\boxed{\text{SE}}} \Psi^1_{\Sigma(t + \Delta)} \qquad \ldots (32)$$

$$\Psi^2_{(\Sigma + O_1)t} \xrightarrow{\boxed{\text{SE}}} \Psi^2_{(\Sigma + O_1)(t + \Delta)} \qquad \ldots (33)$$

$$\Psi^2_{(\Sigma + O_1)t} \xrightarrow{\boxed{\text{SE}}} \Psi^2_{\Sigma (t + \Delta)} \qquad \ldots (34)$$

where SE denotes the Schrödinger equation.

The consequents of (32) and (34) are equal:

$$\Psi^{1}_{\Sigma\,(t+\Delta)} = \Psi^{2}_{\Sigma\,(t+\Delta)} \qquad \ldots (35)$$

If, on the other hand, O_1 measures Σ at time t_m and determines its state function to be $\Psi^{el}_{i\Sigma t_m}$, then the observers can obtain the following predictions:

$$\Psi^{el}_{i\Sigma t_m} \xrightarrow{\boxed{SE}} \Psi^{1}_{i\Sigma(t_m+\Delta)} \qquad \ldots (36)$$

$$\Psi^{2}_{(\Sigma+O_1)t_m} \xrightarrow{\boxed{SE}} \Psi^{2}_{(\Sigma+O_1)(t_m+\Delta)} \qquad \ldots (37)$$

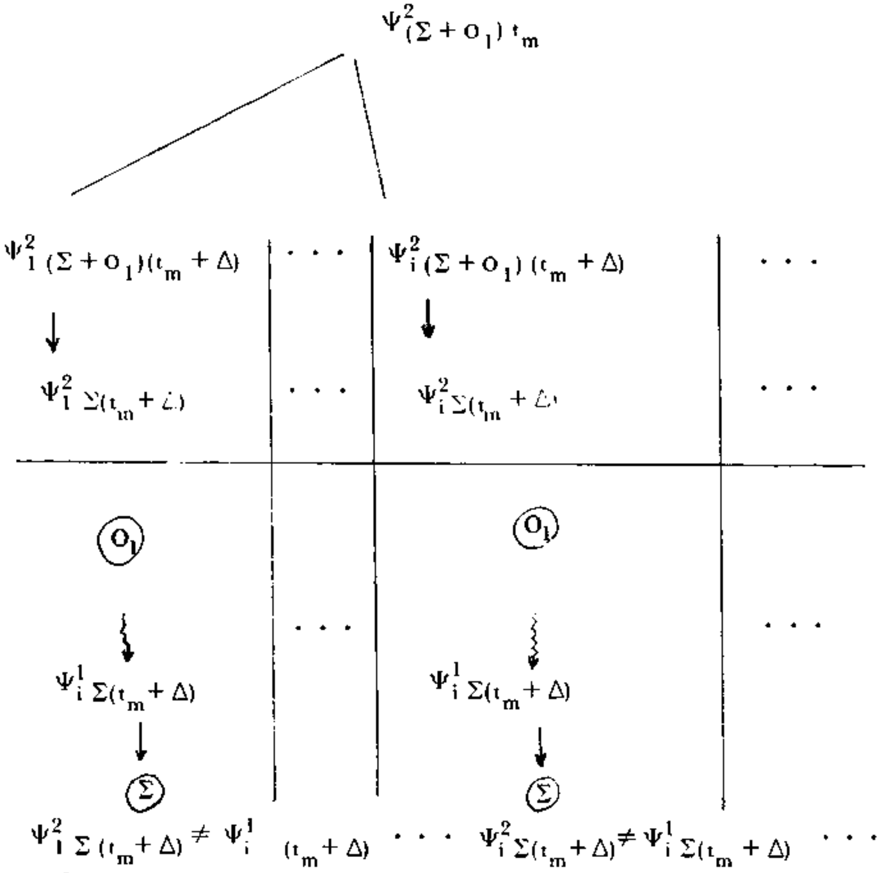
$$\Psi^{2}_{(\Sigma+O_1)t_m} \xrightarrow{\boxed{SE}} \Psi^{2}_{\Sigma\,(t_m+\Delta)} \qquad \ldots (38)$$

where:

$$\Psi^{1}_{i\Sigma(t_m+\Delta)} \neq \Psi^{2}_{\Sigma\,(t_m+\Delta)} \qquad \ldots (39)$$

In contradistinction to CPM, and (31) the two state functions in (39) cannot be set equal by theoretical manipulations.$^{(3)}$

Quantum theoretical considerations of picture 1 induce the following picture with horizontal and vertical epistemic cuts (or epistemic discontinuities) with respect to the observer O_2: (4), (5)



Picture 3.

J. von Neumann has claimed that statements of the form:

a physical quantity has a certain value

do not make sense in QT. What can be meaningful with respect to QT are statements of the form:

an observer has made a subjective observation

which contain an essential reference to measurements.(6);

Such a strict claim might have a justification in the dual nature of the description of dynamics of physical objects in quantum theory.(7) As a consequence of what von Neumann calls the dual nature of the dynamical description, physical phenomena are classified in two categories which are essentially distinct. Classifying physical phenomena either as actually existing in nature or as actually existing in nature's observation, destroys the epistemic objectivity and gives rise to epistemic discontinuities given in picture 3.

In a theory of mechanics, such as quantum mechanics, which contains the above mentioned categories for the description of the dynamics of physical objects, a prediction to be derived from a statement, such as that of CPM, containing empirical factual knowledge is not legitimate because the statement which contains the empirical factual knowledge does not capture the above mentioned dual nature of the dynamical description of objects. Instead, statements which are related to measurements, through which the values of the quantities can be obtained are necessary.

Such a universal propositional function of QT has the following form:

a measurement me measures quantity f
pertaining to Σ at time t with precision
k and result r

Or in short:

$$M_t(me, f, k, r) \qquad \ldots (40)$$

For a definite case, the universal propositional function given by (40) reduces to the following:

a definite measurement me measures
quantity f pertaining to Σ at time t
with precision k_o and result r_o

Or in short:

$$me_t(f, k_o, r_o) \qquad \ldots (41)$$

It should be noted that CPM-cal quantities and QM-cal quantities have been denoted with the same symbol f which might imply that these quantities share the same mathematical and physical properties. However, this is not the case. There are essential measure theoretical differences in the mathematical definitions which are not considered in the present paper.

The empirical knowledge from which the predicted statement is to be derived, can be given by means of $me_t(f, k_o, r_o)$. However, since it is expected (that the *predicted statement will contain probabilistic information in* QT, to model the formal process of prediction the following universal propositional function is necessary:

> in a state of knowledge ρ of the observer
> at time t, probability of measuring quantity
> f pertaining to Σ with the result r is p

Or in short:

$$Pr_t(\rho_t, f, r, p) \qquad \ldots (42)$$

For a definite case, (42) reduces to:

> in a definite state of knowledge ρ of the
> observer at time t, the probability of
> measuring quantity f pertaining to Σ with
> the result r_o is p_o

Or in short:

$$pr_{t(\rho_t)}(f, r_o, p_o) \qquad \ldots (43)$$

Hence, in contrast to the prediction model:

$$h^{e}_{Mt}(f, \alpha_o) \longrightarrow \boxed{} \longrightarrow h_{M(t+\Delta)}(f, \rho_o) \qquad \ldots (44)$$

of CPM, the following prediction model is obtained for QT:

$$me_t(f, k_o, r_o) \longrightarrow \boxed{} \longrightarrow pr_{(t+\Delta)(\rho_t)}(f, q_o, p_o) \qquad \ldots (45)$$

where in fact, (45) amounts to:

$$\mathrm{me}_t(f, k_o, r_o) \longrightarrow \rho_t -\!\!\boxed{}\!\!\rightarrow \mathrm{pr}_{(t+\Delta)}(f, q_o, p_o) \qquad \ldots (46)$$

That is, me_t induces a definite state of knowledge ρ_t for a particular observer at time t, through which a probabilistic prediction is obtained. It can be shown for the CPM limit cases of QM that the prediction model given by (46) collapses to the prediction model of CPM given by (44).

Therefore, the epistemic discontinuity which is a consequence of the wave packet reduction is compensated with the subjective entity ρ_t, i.e., state of knowledge of the observer, which is induced by the measurement me_t, as it is seen from (46) which is a possible model of prediction in QT. Given that causal determinacy in a weak sense and ontic determinacy obtain for QM, it cannot be claimed on the basis of quantum theory that, although quantum theory has been varied and corroborated by nature, the epistemic indeterminacy is an ultimate principle of the micro-cosm. What could be said at most is that quantum mechanics is an epistemically indeterministic theory.

NOTES

1 See 1, p. 14.

2 For an analysis of these propositional functions and those of quantum theory, see 2. However, it should be noted that Scheibe's analysis of these functions is not essentially complete with respect to the actual physical situations.

3 It should be noted that (27)-(30) are given in terms of factual propositional functions, whereas (36)-(39) are given in terms of the state function of quantum mechanics. The state function is not a propositional function. However, on the basis of the state function, the propositional functional counterparts of (36)-(39) can be constructed. Hence, specifying (36)-(39) in the form they are given does not affect what is claimed as a consequence of them.

4 Each vertical branch of picture 3 pictures a possible state of affairs, or a possible world. See 3, and 4.

5 It is believed by some philosophers that each branch can actually exist without possible interactions. For a counter argument see 5.

6 See 6, p. 420.

7 In quantum mechanics, dynamics of objects are described either by a causal or by a non-causal process. By the first, which actually exists in nature is described. By the latter, which actually exists in nature's observation is described. See 6, p. 417-445.

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ÖZET

Epistemik bakımdan determinist bir teoride, ölçmelerde ortaya çıkan etkileşmelerin hesaplanamayacağının varsayılması halinde, bu varsayım, teorinin vermekte olduğu objektif tasviri aralarında epistemik kesintiler olan sübjektif bölmelere indirger. Kuvantum teorisi, ontik ve kozal bakımdan determinist olmakla birlikte, yukarıda belirlenen anlamda epistemik bakımdan indeterminist bir teoridir. Kuvantum teorisinin mümkün kıldığı bir düşünce deneyinin çerçevesi içinde, bu teorinin önerme fonksiyonları kullanılarak bir tahmin modeli oluşturulmuştur. Bu modele dayanılarak kuvantum teorisinde ortaya çıkan epistemik indeterminizmin, bu teori doğa tarafından sağlamlaştırılmış ve doğrulanmış olmasına rağmen doğanın temel bir ilkesi olarak kabul edilemeyeceği ileri sürülmüştür.