STRIFE ABOUT COMPLEMENTARITY (II) *

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5 *Are Atomic Phenomena Unanalysable?*

WE saw (secs. 2 and 3) that, for Bohr and Rosenfeld, the observed system and the instrument of observation form a whole, a 'sealed unit' defining the phenomenon. 'Any atomic scale phenomenon must thus be conceived as a whole; any attempt to apply to it the same kind of analysis as in classical physics would simply make it vanish. The word 'atomic' here resumes its etymological sense with a more subtle connotation.'[1] That is to say, the atomic scale phenomenon is regarded as a whole in the sense of holistic philosophies—a totality that cannot be rationalised and hence represents a limit, a *non plus ultra*, to human knowledge. For instance, every energy change in an atom has to be regarded as elementary or atomic, because the forever indivisible quantum is involved in it;[2] and, as Bridgman once said, 'it is meaningless to penetrate much deeper than the electron', for there is really nothing within it.

This modern version of atomism is as mechanistic as ancient atomism and as irrationalistic as any obscurantist world outlook. The irrationalist feature lies in the claim that wholes are unanalysable, that their analysis and understanding is forever beyond all human possibility. This irrationalist aspect of the official philosophy of quantum mechanics was recognised by Bohr himself, when he wrote that the 'quantum postulate', according to which every atomic process exhibits a character of 'individuality' or wholeness, is an 'irrational element'.[3] Elsewhere, after describing an electron diffraction phenomenon, Bohr stresses the universality of such an irrational totality (which he calls individuality):

> The impossibility of a closer analysis of the reactions between the particle and the measuring instrument is indeed no peculiarity of the experimental procedure described, but is rather an essential property

* Part I of this paper appeared in the May Number.

[1] Rosenfeld, *SC*, p. 395. See also 'L'évolution de l'idée de causalité' (referred to below as *EIC*) *Mém. Soc. Roy. des Sciences de Liège*, 4e. ser., 1942, **6**, 59-87, p. 59

[2] Bohr, *LL*, p. 246

[3] Bohr, *TA*, p. 9

> of any arrangement suited to the study of the phenomena of the type concerned, where we have to do with a feature of *individuality* completely foreign to classical physics.[1]

This *a priori* impossibility of a finer analysis, of the discovery, so to speak, of the fine structure of the disturbance *caused* by the means of observation, was stressed even more sharply in Bohr's last philosophical paper, where we read that, 'in quantum mechanics, we are not dealing with an arbitrary renunciation of a more detailed analysis of atomic phenomena, but with the recognition that such an analysis is *in principle* excluded'.[2] In other words, it is not an arbitrary 'metaphysical' ukase that forbids us to open the sealed unit constituted by the atomic 'phenomenon': now science itself dictates the ukase—*scientia dixit*.

Thus, for the upholders of the usual interpretation of quantum theory, atomic phenomena and their observation are no further penetrable. Instead of atoms of matter, or atoms of motion, we now have atoms of knowledge. This does not mean that the quantum philosophers share the Kantian prejudice of the unknowability of the *Ding an sich*; no, they simply say that nothing is to be known beyond the phenomenon, that the phenomenon is the last stop *in res* as well as *in mente*. This irrationalist attitude was excellently expounded by Schlick, the late leader of the Vienna Circle, in his last paper, where we read: 'Quantum physics teaches inexorably that the detailed prediction of future events is in principle impossible. Hence, it sets upon the knowability of nature an unsurpassable limit. This is just the limit of the possibility of causal prediction.'[3] But this unknowability does not merely consist of the impossibility of knowing something existing *in res*, objectively though in a temporary or even forever hidden way; such processes, elucidates Schlick, are not hidden, they simply *are* not, there is nothing beyond the unsurpassable limits set up by quantum mechanics.

According to positivism, quantum mechanics imposes a *limitation* upon our knowledge and at the same time it gives us a *complete* description of all there is to know. On a materialist theory of knowledge this would be contradictory; on the positivist epistemology it is not. Schlick explains this point, repeating Bohr's contention[4] that quantum

[1] Bohr, 'Can quantum-mechanical description of physical reality be considered complete?' (referred to below as *QMDPR*), *Physical Review*, 1935, 48, 696–702, p. 697

[2] Bohr, *DE*, p. 235, Bohr's emphasis

[3] Moritz Schlick, 'Quantentheorie und Erkennbarkeit der Natur', *Erkenntnis*, 1936, 6, 317–326, p. 317

[4] Bohr, *QMDPR*

mechanics is a complete description of physical reality :

> The quantal laws do honour to the pretension of a complete, exhaustive description of nature in the sense that in principle they say *everything* that there is to say in any language about any natural process. And thus in general : when we say that according to the principles of quantum physics the knowability of nature is anyhow *limited*, this must never be understood as meaning that there is still something beyond the limit, something that will forever remain *hidden* from us. We have not to do here with a limit between known and forever unknown natural laws ; the limit of knowability is at the same time the limit of the lawfulness (*Gesetzmässigkeit*) of nature.[1]

In sum, positivists hold the ancient tenet that nature and knowledge are so to say finite, for they would be composed of ultimate, unanalysable atoms—this time atoms of a funny sort. Scientific materialists, on the other hand, reject ultimate atomism, which is a feature of mechanism, and the irrationalist dogma of the unanalysability of wholes, asserting instead that nature and the knowledge of nature are qualitatively infinite and inexhaustible. They maintain that at every level there are wholes which are so tightly knit, so predominantly determined by their inner motions and the interconnections of their parts, that they actually behave as atomic at their level ; but that there is nothing that guarantees us that these atoms are undecomposable at other levels, so that they may sometimes be regarded as undivid*ed*, but not as indivisible. This holds in particular for the unit formed by subject and object. In sum, scientific materialists reject atomism as an *ultima ratio* and the correlative assertion of the exhaustibility of knowledge.

It is clear why scientific materialists do not accept ultimate limits, as clear as why positivists are pleased in inventing them : it has always been subversive to push research forward, to demand an explanation for everything, to assert that no explanation is final. On the other hand, the positivist acceptance of facts as they are, the irrationalist dogma that there must be some unsurpassable *a priori* limits on knowledge, has always been the conformist attitude. This attitude of resignation, this basically unscientific and conservative attempt to fix *a priori* the scope of research and the depth of explanation is a favourite idea of the quantum philosophers and has been explicitly stated by Bohr in the following words : 'every analysis of the very concept of " explanation " must always begin and end with a resignation regarding

[1] Schlick, op. cit., p. 319

the understanding of our conscious thinking activity.'[1] This attitude reminds one of Leibniz's remark on Descartes's belief that curves could not be rectified : he made this mistake, said Leibniz, out of sheer conceitedness, measuring the forces of the whole posterity by his own forces.

6 *Hypotheses non Fingo*

'No hypothetical element enters into Bohr's interpretation '[2] of quantum mechanics, writes Rosenfeld. It is not clear whether he means here the popular or some of the technical connotations of the word hypothesis ; in either case his contention is wrong. First of all, the so-called principle of complementarity is itself hypothetical in every sense, because it is a more than hazardous conjecture (which is the popular connotation of 'hypothesis'), because it is not directly verifiable (being only one possible interpretation of Heisenberg's relations), and because it is used as the starting point for a host of inferences ; to such an extent that, we are told, 'If we consider it from the standpoint of epistemology, we may be led to modify the theory of knowledge'.[3] The only meaning that might validly be attached to the enigmatic sentence reproduced at the beginning is that complementarity is not a physical but a philosophical hypothesis, as is proved practically by the fact that not a single formula nor a single experiment have been derived from it.

To demonstrate that complementarity is an hypothesis, or a set of hypotheses, and not a factual statement, it will suffice to recall that it is based on several other hypotheses, so that its hypothetical character is of second degree. In fact, the so-called principle of complementarity and the whole philosophy connected with it rest on at least the following hypotheses :

(i) 'The present form of quantum theory furnishes the most complete possible description of physical reality ; in particular, the wave-function furnishes a complete specification of the state of an individual micro-object.' This hypothesis is false, I say, because no theory of reality has ever been verified to be complete nor can be complete in the same sense as a mathematical theory can be complete ; there can be complete theories of ideal objects because these have *by definition* a finite number of qualities. No physical theory could be complete on account of the following axioms underlying every scientific endeavour and confirmed by its failures and successes :

[1] Bohr, *LL*, p. 250 [2] Rosenfeld, *SC*, p. 396 [3] Rosenfeld, *SC*, p. 394

(*a*) nature and every one of its parts is inexhaustible, actually as well as potentially (as regards the parts, in themselves as well as concerning their infinite interconnections) ; (*b*) nature is an interconnected whole, so that the complete specification of a single object would require the complete specification of the whole universe, which is at least practically impossible ; (*c*) knowledge, as its history shows, is as inexhaustible as its objects ; (*d*) we are limited to a finite number of variables (in general, to a finite set of symbols with a finite number of properties), whereas the complete specification of every bit of matter would presumably require an infinite number of variables.

(ii) ' Heisenberg's uncertainty relations (which are an axiom of matrix mechanics and a theorem of wave mechanics, and which are just what the " complementary mode of description " aims at interpreting) are coeternal with quantum mechanics ; no modification of the letter is conceivable which would permit the simultaneous definition of the position and the momentum of a micro-object.' This assumption is clearly as frail as the first, belonging as it does in the same class of metaphysical assertions.

(iii) ' Physics does not deal with " autonomous attributes of the object " but with possible observations and with observables.' This, which is called the principle of observables, is a form of the Berkeleian ' to be is to perceive or to be perceived ', which I think I have refuted elsewhere.[1] Besides being philosophically wrong, the principle of observables contains the germ of its own destruction because, as it is well known,[2] it requires—if one wants the theory to be thoroughly ' operational '—the simultaneous assertion of the converse proposition, namely, ' An arbitrary quantum-mechanical observable, i.e. an arbitrary linear Hermitean operator, is physically observable '. The least that can be objected to this is that it is an unverified statement—which, hence, ought not to integrate a positivistic theory ; for it is plainly impossible to verify that experimental set-ups exist which would permit the measurement of the attributes represented by the operators which our fancy could define.

(iv) ' Atomic energy changes are elementary, or atomic in the etymological sense of the word " atomic ". The quantum is forever indivisible ; in particular, we shall never be able to analyse the exchanges of momentum and energy, so that the limit on knowledge

[1] Mario Bunge, ' New Dialogues between Hylas and Philonous ', *Philosophy and Phenomenological Research*, 1954, **15**, 192

[2] P. A. M. Dirac, *The Principles of Quantum Mechanics*, Oxford, 1947, p. 37

set up by Heisenberg's relations are unsurpassable.' This hypothesis is mechanistic, because it involves an ultimate atomicity, and it is irrationalist, because it asserts an *ignorabimus*. It is certainly true that the quantum of action symbolises a certain level of reality, the atomic level, which is a hard shell to pierce ; but every fact in the history of knowledge, as well as numerous hints coming from the lower levels not covered by the present form of quantum mechanics, suggest that the assumption of such an ultimate irreducible atomicity is wrong ; in any case, such an hypothesis is untestable.

(v) 'The finite or "atomic" interaction between subject and object, the unavoidable and irreducible link of every atomic object with its observer, forces us to abandon the ideal of objectivity and, as a consequence, every form of causality.' This assumption is wrong, in the first place, because there is a consistent *causal* interpretation of the present form of quantum mechanics[1] which is at the same time realistic, and which *retains* the indivisibility of the quantum. In the second place, because the subject-object interaction is, as any other interaction, a *proof* of *some* sort of causality ; only if measurements did not in the least disturb the objects of observation would the causal law cease to be valid. In the third place, because no single theory, however successful, could force us to forego causality, which is the key to scientific explanation ; at most we might be forced (actually we are forced) to abandon temporarily the hope of *predicting* with arbitrary accuracy the outcome of phenomena within a certain level ; but even such a temporary acknowledgment of a limitation upon *epistemological* determinism does not in the least injure *ontological* determinism, i.e. the principle that all things are interconnected with each other in a precise way, regardless of our ability to disclose the form of these connections.

(vi) 'There are two and only two ultimate categories by means of which we can describe atomic experiments : waves and particles, which must always be conceived of in the classical way, though as concepts having a limited range of validity.' This assumption, that particle and wave are the only possible forms of matter, is arbitrary ; nothing warrants that in the future other forms of matter shall not be discovered ; moreover, it is a noxious assumption, for it blocks the way to further advances. The most that might be said is that, up to now, we have not been able to transcend this conceptual limitation.

[1] Bohm, *IQT*

Thus, it is not true that 'the complementarity idea is first of all the most direct expression of a fact',[1] it is not true that Bohr does not feign hypotheses when he speaks of complementarity. What is true is that the doctrine of complementarity is not a physical one—nor a right one.

7 *Complementarity in Classical Physics?*

Following Bohr's suggestion,[2] Rosenfeld wants to extend complementarity to classical physics—which shows once again that complementarity is not a necessary outcome of modern atomic physics but a philosophical tenet. The idea of this extension is that in both fields our knowledge is imperfect, the nature of measurements preventing us from uniting all data in a unique conceptual model. Thus, we are told[3] that the microscopic and the macroscopic or thermodynamical aspects of the evolution of a physical system stand to each other in a relationship of complementarity; in other words, the variables energy and temperature would be complementary to each other. The grounds for this conclusion are the following:[4] (1) energy is a mechanical variable (what would Ostwald have said of this?), because it serves to define a system in statistical mechanics; whereas temperature is, like entropy, a thermodynamical variable by means of which we perform the thermal description of the same system that is described mechanically by means of energy; (2) energy and temperature are complementary to each other because, if one measures energy, thereby fixing its value, one is not able to ascertain the value of the temperature with arbitrary accuracy; and conversely, the equalisation of temperature that takes place when we intend to measure it produces several possible energy distributions, that is, a latitude in the value of the energy—and this is interpreted in the sense that the system has no definite energy, or is in no definite energy state.

It is clear that this extension of complementarity is a consistent application of the basic epistemological principle of subjective idealism: *esse est percipi*. The system *has* no temperature, it is argued, if the observable temperature is not being measured; it *has* energy only when we attempt to measure it (Destouches would say when we have

[1] Rosenfeld, *SC*, p. 396

[2] N. Bohr, 'Chemistry and the Quantum theory of atomic constitution' (referred to below as *CQT*), *Jour. Chem. Soc.*, 1932, pp. 349–384

[3] Rosenfeld, *SC*, p. 398

[4] Rosenfeld, *SC*, and 'The foundations of statistical mechanics', lecture, São Paulo (Brazil), August 1953

the intention of measuring it). It is also clear that one of the premisses of the argument, namely, that energy is an exclusively mechanical variable and temperature an exclusively thermal variable, is wrong; in fact, both can be introduced in a phenomenological (non-mechanical) way for matter in bulk, as is done in thermodynamics; or in an analytic way, as is done in statistical mechanics. Furthermore, the thermodynamic and the microscopic descriptions do not provide 'aspects' on an equal footing, as Rosenfeld assumes, but different levels of analysis disclosing correspondingly different levels of matter, each characterised by specific qualities (for example, temperature has a sense only for large aggregates of atoms). And, since no relation of complementarity is conceivable between concepts and conceptual systems referring to different levels, the microscopic and the thermodynamic descriptions cannot be regarded as complementary to each other. (It might be argued, in favour of Rosenfeld, that mechanism ignores levels.)

But all this is a trifle compared with the following discovery of the idealistic interpretation of statistical mechanics: the irreversibility of natural processes taking place in matter in bulk would be a consequence of our ignorance. Here is the proof demanded by the sceptical reader: 'The irreversibility arises from a statistical element superimposed upon the elementary laws, namely, the incompleteness of our knowledge of the initial conditions which determine the evolution of the system in virtue of those laws.'[1] This is an old idea of Bohr,[2] who more than twenty years ago stated that irreversibility is not a quality of processes at the macroscopic level (not a quality of wholes that is absent in each of its parts taken isolated from the others)—but a property of *our* description of them. Irreversibility, he explained, 'does not mean that a reversal of the course of events is impossible, but that the prediction of such a reversal cannot be part of any description involving a knowledge of the temperature of the various bodies'.[3] The same would happen in quantum mechanics: there is reversibility in the laws of motion, but

> essential irreversibility in the physical interpretation of this symbolism. In thermodynamics as well as in quantum mechanics the description contains an essential limitation imposed upon our control of the events which is connected with the impossibility of speaking of well-defined phenomena in the ordinary mechanical sense.[4]

[1] Rosenfeld, *SC*, p. 397
[2] Bohr, *CQT*
[3] Bohr, *CQT*, p. 376
[4] Bohr, *CQT*, pp. 376-377

Now, this supposed essential, inherent, unsurpassable limitation upon knowledge (exemplified by the ignorance of the initial values) seems to have quite magic effects : first, it produces irreversibility ; second, it produces—a deeper knowledge. As to the first effect, it is plain : it is just our imperfect knowledge of the initial conditions 'which defines the thermodynamic behaviour of the system '.[1] Thus, according to Bohr and Rosenfeld, irreversibility would not be an objective feature of material systems at the macroscopic level, a result of a given type of interactions between its parts, but a result of the limitation of our analysis of them. As soon as we improve observations, Rosenfeld maintains,[2] irreversibility disappears ; so that, if we want to take it into account, we have to stop our analysis superimposing on dynamics an irreducible ' statistical element ' (namely, finite cells in phase space). This resignation to ignorance, as Born[3] puts it in a similar presentation of this problem, far from being temporary is ' fundamental and inevitable '. And this is the second magic effect of ignorance : that it gives us a wonderful body of laws of nature in the form of statistical mechanics ; if further amplified by adding the postulate of the impossibility in principle of knowing the details of the microscopic behaviour of the system, then this peculiar brand of ignorance gives us an even deeper level of knowledge, namely, quantum statistics. How magic this sort of ' dialectics ' is !

To sum up, Bohr and Rosenfeld's idealist interpretation of thermodynamics and statistical mechanics contains the following philosophical hypotheses : (1) the idealist (or operationalist) axiom that a system has no energy (or no temperature) as long as we do not measure it ; (2) the idealist inference that irreversibility, that conspicuous trait of nature, is a consequence of our ignorance of details—which might be called the paradox of haughty humility ; (3) the curious opinion that, the more we ignore, the more we know—which is the paradox of the *docta ignorantia ;* and (4) the mechanistic principle that chance is irreducible and, moreover, the basic mode of behaviour, for phenomena have, according to Rosenfeld, ' a proper statistical character, inherent in their nature and accordingly irreducible '.[4]

[1] Rosenfeld, *SC*, p. 397

[2] Rosenfeld, lecture mentioned above

[3] Max Born, ' Le second principe de la thermodynamique déduit de la théorie des quanta ', *Annales de l'Institut Henri Poincaré*, 1949, **11**, 1-13, p. 6

[4] Rosenfeld, *SC*, p. 397

8 *Is Complementarity the only possible Rational Interpretation ?*

Rosenfeld claims that 'complementarity appears as the only possible rational interpretation' of quantum mechanics.[1] Moreover, that 'The first point to realise is that the conception of complementarity forces itself upon us with logical necessity'[2]—as if it were a theorem, not a hypothesis. The aprioristic, dogmatic character of this contention is still more clearly shown in the prophecy that 'Whatever form the future theory will take, it will have to embody complementarity as a limiting case, just as complementarity itself embodies classical determinism'.[3] At the end of his allegation, Rosenfeld grants that 'complementarity is just a stage which we shall soon have to leave behind us'[4] in a sort of 'dialectical' negation because, we are told, 'the future theory will reinforce complementarity by fixing its place within a still wider synthesis'.[5] Thus, first we are told that complementarity is the dialectical negation of determinism, which henceforth enjoys only a limited validity, namely at the macroscopic level; now we are told that 'the' future theory, far from dialectically negating complementarity, will *reinforce* it—which sounds like a mechanistic interpretation of dialectics, in so far as it suggests that the negated or sublated term remains unaltered, only its context changing with its negation. If applied to sociology, this view of dialectical negation might produce funny theories.

This strange prophecy on the *future* of quantum mechanics, presumably originating in supernatural revelations, is offered just as an antidote against the deterministic interpretations of quantum mechanics which have been recently advanced, and which, according to Rosenfeld, 'are all doomed to one fate'.[6] Why? Because they are less rational than 'the only possible rational interpretation'? [7] Presumably. But, if this is so, we are faced with a new paradox, which may be schematised as follows: (1) the orthodox interpretation is the only rational one (and the only *possible* rational one at that!)—but, as Bohr [8] and Rosenfeld [9] have repeatedly asserted, it sets a limit upon rationality, upon the understanding of facts, it leaves an irreducible irrationality. (2) The non-orthodox interpretations are tacitly accused of being non-rational or at least less rational than the orthodox one [10]—whereas

[1] Rosenfeld, *SC*, p. 399
[2] Rosenfeld, *SC*, p. 394
[3] Rosenfeld, *SC*, p. 402
[4] Rosenfeld, *SC*, p. 408
[5] Rosenfeld, *SC*, p. 409
[6] Rosenfeld, *SC*, p. 403
[7] Rosenfeld, *SC*, p. 399
[8] Bohr, *TA*
[9] Rosenfeld, *EIC*
[10] Rosenfeld, *SC*, p. 400

they endeavour to transcend the limits set upon the rationality of atomic phenomena by the official philosophy of quantum mechanics and, at least as far as Bohm's causal interpretation [1] is concerned, Rosenfeld himself acknowledges that it is self-consistent.[2] As Kierkegaard said, religion is made of absurdities and paradoxes—and that is why it must be believed.

Let us take a look at one of those 'doomed' deterministic interpretations. We shall limit ourselves to Bohm's work, which according to Rosenfeld 'is very cleverly contrived' [3] and which is just the one that provoked the present rain of attacks on that author as well as on de Broglie and other physicists that have dared to object to the orthodox faith. In my opinion, Rosenfeld makes two basic mistakes in his short exposition of Bohm's ideas. The first is his contention that Bohm has given a description of atomic phenomena 'entirely in the spirit of corpuscular mechanics', regarding the de Broglie wave as merely 'an auxiliary concept'.[4] It is enough to glance at Bohm's papers to see that he explicitly *postulates* the objective reality of the ψ-field, as well as the objective reality of the particle aspect of micro-objects. Now, it is astonishing that, of all the persons in the world, it is Rosenfeld who should criticise the hypothesis of the unreality of the de Broglie waves. It is just in the Bohr-Heisenberg interpretation that they are regarded as merely a conceptual tool (not even as a conceptual model of reality) enabling one to calculate probabilities —whence their name of 'probability waves' or even of 'waves of knowledge', as well as the absurd expression 'interference of probabilities'. In the orthodox interpretation we have neither particles nor waves, but only a pair of 'conjugate concepts'.[5] It is Bohr, not Bohm, who regards the wave-functions as merely 'symbols helpful in the formulation of the probability laws governing the occurrence of the elementary processes'.[6] In general, the formulae of quantum theory are regarded in the orthodox interpretation as statements about observable 'phenomena' which do not assert anything about the real world. Why then should Rosenfeld dislike Bohm's non-existent elimination of the ψ-waves from reality?

The second important mistake made by Rosenfeld in his hasty critique of Bohm's interpretation is his contention that, after all, it ends in complementarity, because when one measures the 'hidden parameters' describing the real position and the real momentum of the

[1] Bohm, *IQT* [2] Rosenfeld, *SC*, p. 403 [3] Rosenfeld, *SC*, p. 403
[4] Rosenfeld, *SC*, p. 403 [5] Rosenfeld, *SC*, p. 395 [6] Bohr, *CQT*, p. 370

electron, one falls back into the uncertainty relations. This is wrong, because in the causal interpretation those parameters describe objectively existing qualities, that is, qualities possessed by the electron even when we shut the lab and go to sleep—whereas in the usual interpretation they exist only in so far as they are 'conjured up' by the experimenter (to use Rosenfeld's words [1])—who is supposed to act as a magician. Of course the experimental determination of these attributes is subject to error, since we know nature best by modifying it—but this time the uncertainties are regarded (1) as a practical limitation, not as an eternal curse, (2) as effects of a *real disturbance* exercised on *real* objects. In the usual interpretation we cannot say that the instruments disturb the object, for this implies that the latter exists objectively; that is to say, the measurement is not regarded as producing a real disturbance in the original path and velocity of the micro-object, it is deemed to produce only a discontinuous and unpredictable change in the wave function (from a general state into an eigenstate of the measured observable), which in turn has no other physical meaning than that of a probability amplitude. Thus, in the usual interpretation, before the measurement the micro-object was in no definite state at all (and even it cannot be said to have existed), whereas in the causal interpretation, if I understand it correctly, the measurement act changes the system from one precisely defined and real state into another precisely defined and real state, although the former may not be known experimentally with sufficient accuracy. So that Heisenberg's relations are retained in Bohm's interpretation—as was to be expected since he does not change Schrödinger's equation; but they are not *interpreted* as relations of complementarity, and this is just Bohm's point. Moreover, they are not conceived as eternal; future theories, which are certainly badly needed, might change those relations, showing that they have a limited domain of validity. Rosenfeld misses this point because he identifies the uncertainty relations with their positivistic interpretation, namely, the doctrine of complementarity.

Nearly twenty years ago Castelnuovo, the distinguished mathematician, expressed an opinion that was then a warning and is still a lesson of prudence:

> It is always necessary to take into account that science will never be completed and that the progress of observations and of theory may lead from the present anti-deterministic phase to a deterministic phase

[1] Rosenfeld, *SC*, p. 393

—which, in turn, may be followed in the future by several similar alternatives.[1]

9 *Conclusions*

Our main conclusion is that the usual interpretation of quantum mechanics is neither the only possible rational one nor is it in agreement with scientific materialism. It is, on the other hand, consistent with the principles of logical empiricism, particularly with the Berkeleian theory of knowledge.

Not the least merit of the recent causal interpretations of quantum mechanics proposed by de Broglie,[2] Bohm,[3] Jánossy,[4] Novobatzky,[5] Takabayasi,[6] Vigier,[7] and others, as well as of the untiring criticisms of Einstein [8] and of Schrödinger,[9] is that they are awakening us from the dogmatic slumber (as Kant would say) in which most of us have been sunk. It has been proved in practice that complementarity is not the only possible interpretation of quantum mechanics. And this has made it possible to suggest several ways out of the present stagnation of theoretical physics, a stagnation which is certainly due in a large measure to the dogmatism with which the official philosophy of quantum theory has been maintained.

From now on no reflective theoretical physicist will have the right to utter words such as these:

> See how neatly the statistical predictions of quantum mechanics are adapted to the interpretation of the experimental results! They are all susceptible to verification and they embody every single detail that experience reveals to us. Neither too much nor too little: what more do people want?[10]

[1] Guido Castelnuovo, 'Il principio di causalità', *Scientia*, 1936, **60**, 61–68, p. 68

[2] Louis de Broglie, *La physique quantique, restera-t-elle indéterministe?* Paris, 1953

[3] Bohm, *IQT*

[4] L. Jánossy, 'The Physical Aspects of the Wave-particle Problem', *Acta Physica Hungarica*, 1952, **1**, 423–467

[5] K. F. Novobatzky, *Annalen der Physik* (6), 1951, **9**, 406; 1953, **11**, 285

[6] T. Takabayasi, *Progress of Theoretical Physics*, 1952, **8**, 143; 1953, **9**, 187

[7] Jean-Pierre Vigier, *C.R. Acad. Sci.*, 1951, **233**, 1010; 1952, **234**, 410; 1952, **235**, 1107

[8] A. Einstein, B. Podolsky, and N. Rosen, 'Can Quantum-mechanical Description of Physical Reality be Considered Complete?' *Physical Review*, 1935, **47**, 777–780. See also Einstein's 'Autobiographical Notes' and 'Reply to Criticisms' in P. A. Schilpp (Ed.), *Albert Einstein: Philosopher-Scientist*, Evanston, Ill., 1949

[9] Erwin Schrödinger, 'Are there Quantum Jumps?' this *Journal*, 1952, **3**, 109–123, 233–242. See also *Endeavour*, 1950, **9**, 109–116 and *Scientific American*, 1953, **189**, No. 3, 52

[10] Rosenfeld, *SC*, p. 404

From now on more and more people want to understand formulae, not merely to calculate them ; from now on more and more people want to leave behind the present stagnation, more and more people are realising that this will be possible only by foregoing the positivistic philosophy which the doctrine of complementarity integrates. Their attitude will resemble more and more the free and fearless attitude which Harvey[1] described three centuries ago :

> True philosophers, who are only eager for truth and knowledge, never regard themselves as already so thoroughly informed, but they welcome further information from whomsoever and from wheresoever it may come ; nor are they so narrow minded as to imagine any of the arts or sciences transmitted to us by the ancients, in such a state of forwardness or completeness, that nothing is left for the ingenuity and industry of others. On the contrary, very many maintain that all we know is still infinitely less than all that still remains unknown ; nor do philosophers pin their faith to others' precepts in such wise that they lose their liberty, and cease to give credence to the conclusions of their proper senses.

[1] William Harvey, *Exercitatio Anatomica de Motu Cordis et Sanguinis*, Dedication (1628), *apud* W. T. Sedgwick and H. W. Tyler, *A Short History of Science*, New York, 1917, Appendix D