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Holism in microphysics

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ABSTRACT. The concept of holism seems to have gained its present popularity in intellectual circles mainly as a result of certain developments in twentieth century physics. The aim of this article is to identify and discuss briefly these developments and their precise import to the issue of holism. In the Introduction, holism is characterised as the failure, within a given theoretical framework, of the so-called method of analysis, according to which objects can be treated as conceptually divisible into ontologically independent parts. In Section 2, it is explained how the issue of holism arises in our basic theory of matter, quantum mechanics (QM). It is shown, in particular, how this issue is linked with the long-lasting controversy over the completeness of the quantum theoretical description of reality. Section 3 is dedicated to the examination of the simplest kind of quantum mechanical systems displaying holism, namely, the pairs of correlated objects first studied by Einstein, Podolsky and Rosen (EPR) in their famous 1935 article. It is shown in some detail why, and in what sense, these objects form a single un-analysable "whole". The contrast between this unique theoretical description and those typical of classical theories is illustrated through a simple example. Section 4 analyses a different form of holism, which was introduced by Niels Bohr along his struggle to defend the completeness of QM. It is argued that this form of holism does not derive from quantum mechanical holism, as exhibited for instance, in the EPR systems. It is argued further that Bohr's holism suffers from several conceptual shortcomings, despite its powerful historical influence. Finally, Section 5 deals with a form of holism associated with David Bohm's hidden-variables theory. It is shown that although this theory and, generally, any hidden-variables theory, exhibits several strange, non-classical aspects, holism is *not* among them, contrary to what is commonly assumed in the literature. In particular, the distinction and independence between non-locality and holism is underlined. In the Conclusions, it is pointed out briefly that none of the forms of microphysical holism identified in this article seems to warrant the sweeping assertions on holism frequently found in unspecialised literature, to the effect that the world at large constitutes a single, indivisible whole.

1. INTRODUCTION

From Greek antiquity down to the present day, *analysis* has been a central methodological element in man's endeavours to explain natural phenomena. It can be characterised as the prescription that, in the effort to understand an object or process, it should be conceptually "divided up" in parts. It is hoped that in this way simpler, more tractable elements are found, whose nature and operations help us to understand the complex object or process.

The application of the method of analysis helped ancient philosophers to formulate several theories on the nature of bodies, purporting to show how their properties and interactions result from the operation of certain elementary constituents. Atomism and the doctrine of the four elements were perhaps the most important of them. Modern and contemporary science provide countless examples of successful use of the method of analysis. Physical science, in particular, successfully describes most physical systems as composed of well-defined parts, which preserve their individuality by entering into composition.

The word *holism*, as it is used nowadays, has a wide variety of senses (see e.g. Esfeld [2001] and Healey [1991]). In this essay we shall take it as meaning the breakdown of the method of analysis. In other words, an object will be said to be *holistic* if it cannot be understood as consisting of ontologically independent parts.

This characterization of holism is theory-dependent, since what matters here is the *theoretical* understanding of the object. Any attempt to avoid the theoretical relativization of the concept would take us to the realm of metaphysics. The bald assertion that the world contains objects that are in themselves uncompounded, for instance, does not appear to have much scientific cash value. This does not mean, however, that we must reject any speculation on the nature of reality. Some philosophers, the scientific realists, argue indeed that our best scientific theories do have something to say about reality, even if what they say is recognized as being fallible. Scientific realists claim that at least in certain cases there may be good reasons for expecting that certain theoretical entities or aspects will be preserved as science progresses. Concerning the particular issue of holism, we shall see in the sequel that certain results in microphysics do indeed provide unusually strong evidence for a specific form of holism, which we can then tentatively ascribe to the real world.

In his incisive analysis of the issue of wholes and parts, Abner Shimony ([1993], chapters 14 and 15) draws the distinction between the “ontological” and the “epistemological” aspects of the problem. The former corresponds approximately to the above characterization of holism. Since it implicitly involves theories, and theories are part of human knowledge, Shimony’s choice of words does not seem entirely appropriate. In our opinion, the aspect of the problem which should more properly be called ontological is the holistic (or otherwise) character of reality itself. And, as we have indicated, the discussion of this point in isolation from our theories would belong to the unfathomable domain of metaphysics. As to Shimony’s “epistemological” aspect of the parts-wholes problem, it should perhaps be called its *practical* aspect, since it refers just to the experimental and computational difficulties typically encountered in the practical treatment of composite systems. This aspect will not be explored in this essay; Shimony's articles should be consulted for an insightful philosophical analysis of its import to the ontological, conceptual and theoretical facets of the problem.

2. THE COMPLETENESS OF QUANTUM MECHANICS

At the end of the nineteenth century and beginning of the twentieth, several theoretical and experimental developments established the reality of atoms beyond reasonable doubt. Ironically, however, in the same period another set of results began to reveal that atoms, as postulated in Dalton's chemical theory, for instance, still had parts, such as electrons and alpha particles. The subsequent development of physics led to further partitions, so that nowadays the existence of truly atomic, indivisible entities is again an open question.

What is certain is that in the mid-1920's the whole class of micro-entities which contemporary physics takes as forming material objects was encompassed by a remarkably successful theory, quantum mechanics (QM). No phenomenon is known to disconfirm any of the quantum mechanical predictions. Notwithstanding, QM displays several extremely puzzling conceptual aspects, among which is a rather peculiar form of holism.

The issue of holism first arose in QM in connection with the discussion of its theoretical completeness. Strong suspicions that QM does not say everything there is to be said about the properties of objects were voiced by three founding fathers of the theory: de Broglie, Schrödinger and Einstein. The primordial source of these suspicions is the peculiar way in which QM ascribes properties to objects.

When information about a physical object is maximal in QM, its state is described by mathematical entities called *wavefunctions* (or, more generally, vectors in Hilbert spaces). However, each wavefunction yields the values of *some*, but *not all*, physical magnitudes ordinarily considered to belong to the object.[1] This suggests that the theory fails to afford a complete description of the properties of the object, and the fact that the magnitudes whose values are not specified by a given wavefunction *can* nevertheless be measured in the usual way only contributes to enhance this impression.

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[1] In the formalism this is expressed by the fact that no wavefunction is a simultaneous eigenfunction of all the operators in Hilbert space corresponding to these magnitudes.

The initial rebuttal of this argument was based on the claim that the existence of the "quantum of action" implies that in the act of measurement or observation – whatever it is – an unavoidable and uncontrollable disturbance is introduced in the observed object. Heisenberg, Bohr and others argued that such a disturbance entails the impossibility of *knowing* simultaneously all the properties of the object. Positivism was then invoked (often implicitly) to justify the completeness claim: one should not expect physical theory to describe properties which are in principle unknowable.

It is beyond the scope of the present work to explain why the above justification of completeness fails, even if positivism is taken for granted (see e.g. Brown and Redhead [1981]). We just wish to remark that by the mid-1930's the completeness thesis was already prevalent, and that the disturbance assumption was central in its defence. In 1935, Einstein and two collaborators devised an ingenious argument, now known as the "EPR argument", exactly to show the limitations of this assumption (Einstein, Podolsky and Rosen [1935]).

3. EPR "ENTANGLED" STATES: QUANTUM MECHANICAL HOLISM

The EPR argument cleverly exploits the existence of certain correlations between spatially separated, apparently non-interacting objects, which have been produced by a common source. These correlations follow from the formalism of QM and, as we know today, are verified experimentally.

For the sake of simplicity, let us consider the version of the argument formulated by David Bohm [1951]. In this case, the EPR systems are formed by two spin-½ objects, such as electrons, and the correlated properties are spin components. As is well known, for this kind of object these properties are bivalent. Let us call them 'S' and take their values to be +1 and –1. When the system is prepared in a special quantum state, the singlet state, QM predicts that the *results of measurements* of spin components along the same direction on the two objects are strictly anti-correlated: if one is +1 the other is –1, or vice-versa (which of these cases actually obtains is a matter of pure chance, according to the theory).

This kind of correlation can easily be explained by assuming that, as any classical property, S has a definite value all the time and is subjected to a conservation law. The correlation is physically established when the pair of objects is produced in the source. When the objects fly apart, each carries its intrinsic S property all the time, and the measurement just reveals its particular value.

Oddly enough, this classical, intuitively plausible explanation is *impossible* if QM is considered complete. As it happens, even though the singlet state attributes an S value 0 to the *joint* system, it does not attribute any value to the property S to the *individual* objects before measurement. According to the theory, when each object is heading toward its S measurement device, it just does not have any S value at all! The fact that the two measurement results are always correlated comes then as a miracle.

Einstein correctly realized that the *only* way out would be to assume that there is some kind of non-local influence reaching instantaneously from one object or apparatus to the other: upon the "appearance" of an S value in one of them the other would be "informed", so that it can "choose" the right value to display. Besides its weirdness, this alternative explanation seems to be in conflict with relativity theory, which forbids physical influences travelling faster than the speed of light (and the EPR systems can be arranged as to require violation of this limit).

Einstein has then concluded that the trouble with the EPR correlations is the way quantum states attribute properties to physical objects. Indeed, what blocks the classical, ordinary explanation for the correlations is just the lack of definite S values in the individual objects before measurement, when the system is in the singlet state. The description of the physical properties of objects by way of quantum mechanical states is, therefore, *incomplete* (but not *wrong*, as far as it goes).

We shall not discuss the details and implications of the argument here, since this has been done elsewhere (see e.g. Chibeni [2001]); we shall limit ourselves to underlining its aspects related to holism. As we have pointed out, the quantum mechanical description of the EPR systems displays the curious aspect that, while the singlet state attributes a definite value to the property S of the total system (namely, 0), it fails to ascribe any value at all to the same property of its components. The whole has, thus, a property which cannot be reduced to the properties of the parts. This is a clear case of breakdown of the method of analysis; the EPR systems are, therefore, holistic, according to QM.

One of the fathers of QM, Erwin Schrödinger, thought that this was "the most difficult and interesting point of the theory" ([1935], p. 331) and, famously, used the word *entanglement* to refer to this theoretical aspect. In an important article published in 1935, he worked out its maths and drew from it an entirely new argument for the incompleteness of QM (Schrödinger [1935]). The argument was, of course, welcomed by Einstein (who had, by the way, independently devised a formally analogous argument). Schrödinger's argument became known as the "cat" argument, and can also be construed as pointing to the existence of a serious problem in the foundations of the theory, the "measurement problem".[2]

In classical physical theories – Newtonian mechanics, for instance – two-body systems exhibiting empirical correlations identical with those of the EPR systems would be regarded as consisting of two ontologically independent entities; properties could be ascribed to each of them regardless of the other component. This does not mean, of course, that these parts cannot interact. But although classical physical actions of one object on another change its properties, they do not destroy its ontological independence. The method of analysis capitalizes exactly on this point.

By contrast, the quantum mechanically entangled EPR systems cannot be treated as composed of two ontologically independent parts; they form "wholes". It is important to notice, however, that such quantum mechanical wholes are not perennial. They seem, on the contrary, to be rather fragile. The determination of the exact circumstances capable of leading to their dissolution is currently the subject of intense theoretical and experimental investigation.[3] When, for one reason or another, holistic quantum systems "break up", independent parts reappear instantaneously, perhaps in remote regions of space.

The contrast between the classical and the quantum mechanical treatments of the EPR correlations can be made clearer by means of a simple comparison. Suppose you take an ordinary pair of gloves and separate the two gloves blindly and at random, putting them into two boxes. The boxes are them closed and transported to distant, non-interacting regions of space. Attribute now, by convention, the values '+1' to right-handed gloves and '–1' to left-handed ones. From the way the system has been prepared, you know that the joint system has a total "glove" value 0. Common sense and classical scientific theories tell you that this property of the system can be conceptually analysed as resulting from the individual

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[2] The discussion of this argument goes beyond the scope of the present essay. Notice, however, that although both the EPR and the cat argument start from the same point, quantum entanglement, and end in the same conclusion, the incompleteness of QM, the structures of the arguments are entirely distinct. In a nutshell, the former shows that the assumption of completeness leads to the apparently unacceptable conclusion that physically real, non-local influences connect the entangled objects. And the latter shows that, on the assumption of completeness, entanglement transfers the ontological blurring or indeterminateness of properties from the micro to the macro world, where it has never been observed (and is not even conceivable).

[3] There is a growing perception that measurements cannot be the only situation in which this occurs, as it was once believed by some proponents of the orthodox interpretation of QM.

properties of its components, even though in this case you actually lack specific knowledge about the values of these individual properties. The fact, then, that upon inspecting the contents of one box you can immediately infer the value of the distant glove comes as no surprise. This is a purely epistemic phenomenon, and does not involve any kind of physical influence between the gloves, or between you and the distant glove. Before the act of observation, you had a partial, incomplete knowledge of the objects, but this did not preclude the conceptual application of the method of analysis. Einstein effectively argued that quantum mechanical entanglement in the EPR systems should likewise be understood as arising from the incomplete specification of real properties by the wavefunctions. The correlation of the *measured* properties is to be explained by the correlation of real, pre-existing properties of the objects (which were individually unknown before measurement). No physical action-at-a-distance, no breakdown of the method of analysis, and no proof of holism in the world would be implied by this situation.

4. BOHR'S HOLISM

The EPR argument forced Bohr to change his strategy for defending completeness. The idea of a physical "disturbance" upon measurement no longer sufficed, since knowledge about the S property of the distant object can be obtained just by inspecting the "local" object. And even Bohr acknowledged that there is no *physical* influence from one branch of the experiment to the other. The theoretical lack of properties in individual objects could not, therefore, be positivistically justified by the putative impossibility of knowing them due to an uncontrollable physical disturbance. The failure of QM to specify these properties before the act of observation should, therefore, be attributed to its incompleteness.

To meet this challenge, Bohr resorted to the idea that a strange, *non-physical* kind of influence binds the object and the *"observing agent"*. According to Bohr, the observing agent (which includes the whole experimental arrangement, in *both* branches of the experiment) would determine an "influence on the very conditions which define the possible types of predictions regarding the future behaviour of the system". These conditions, he adds, "constitute an inherent element of the description of any phenomenon to which the term 'physical reality' can be properly attached ..." (Bohr [1935], p. 700). Now, the original EPR argument depends on the consideration of the values of two physical quantities (in Bohm's example, spin components along orthogonal directions) whose measurement would, according to the orthodox view, require mutually exclusive measuring apparatuses (a point to which the above simplified exposition does not do full justice). Since, according to Bohr, the very possibility of *talking* about physically real objects and their properties depends on the "whole arrangement" (ibid, p. 698), even when this includes apparatuses lying in remote, physically isolated regions, the EPR argument involves an essential "ambiguity" (ibid., p. 700; see also [1949], p. 234), and is thus invalid.

The proposed interconnectedness of objects and the whole experimental context, including the observing agents, has been described by Bohr and some of his followers as a kind of holism. Indeed, references to the "*whole* experimental arrangement" as conditioning the meaningful, "unambiguous" ascription of properties to objects abound in Bohr's writings on the foundations of QM (see e.g. [1949], pp. 230, 238). It is this holism that would, according to him, preclude the application of the method of analysis to the EPR systems, as implicitly required by Einstein's argument.[4]

It should be stressed, however, that Bohr's holism is not the same as, and does not derive from, the quantum theoretical holism inherent in quantum-mechanically entangled systems. Apparently, Bohr has never explicitly compared the two concepts. Whereas quantum mechanical holism is an objective aspect of the quantum formalism itself, Bohr's holism is neither formal nor physical, being, rather, philosophical. This form of holism intermingles ontological, epistemological and even linguistic issues into an unholy alliance.

Furthermore, Bohr's holism seems to be entirely *ad hoc*, since it has been purposely devised to evade the EPR incompleteness argument, with no independent justification or application in physics. Finally, it can be shown that it is innocuous against a modified form of the incompleteness argument, foreseen by Einstein himself and worked out by other students in more recent times (Fine [1986], Redhead [1983], Hellman [1987]). In this streamlined version the argument does not involve alternative measuring apparatuses, breaking thus the kernel of Bohr's reasoning. For all these reasons we do not consider Bohr's holism as an

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[4] Replying to one of Einstein's articles, Bohr explicitly evoked the failure of the method of analysis, arguing that in quantum mechanics "we are not dealing with an arbitrary renunciation of a more detailed analysis of atomic phenomena, but with a recognition that such an analysis is *in principle* excluded" ([1949], p. 235; Bohr's emphasis). And in an address at the University of Columbia in 1955 he stated that "The essential wholeness of a proper quantum phenomenon finds indeed its logical expression in the circumstance that any attempt at its well-defined subdivision would require a change in the experimental arrangement incompatible with the appearance of the phenomenon itself" ([1958], p. 72; see also [1949], pp. 210, 222).

interesting subject for further research, despite its undeniable influence on the establishment of the orthodox, "Copenhagen" interpretation of QM.

5. BOHM'S HOLISM

In the two decades following Einstein's and Schrödinger's attack on, and Bohr's obscure defence of the thesis of the completeness of QM, very little work was done on the crucial issues raised by the arguments. The debate was finally resumed as a result of the inception, in 1952, of Bohm's hidden-variables theory (Bohm [1952]). Generally speaking, *hidden-variables theories* (HVT) are theories purporting to supply what is apparently missing in the quantum mechanical description of reality. Given the weight traditionally attributed to Bohr's arguments for the completeness of QM and to an "impossibility" theorem proved by von Neumann [1932], few people still believed that consistent, empirically adequate HVTs could be devised. But Bohm has done the impossible. The price is that, although the theory provides a complete value assignment, thereby reinstating the analysability of complex systems, it generates its own conceptual and theoretical puzzles.[5]

First, in Bohm's theory the quantum states are supplemented by certain "hidden" (i.e. non-quantum mechanical) variables, so that they jointly supply the values of the apparently missing properties, but no one has yet discovered a way to cash this out in practical terms. In other words, although the theory allows for this possibility, in its present state it has no new empirical predictions as compared to QM.

Secondly, the theory displays a very peculiar trait, *non-locality*, meaning the possibility of instantaneous influences between physical objects lying arbitrarily apart one from the other. In particular, non-locality is present, according to Bohm's theory, when the objects are quantum-mechanically entangled. This is a piece of historical irony, for, as we have seen, locality was the central premise in Einstein's argument for the incompleteness of QM.

The irony has become dramatically acute as a result of John Bell's proof, in 1964, that not only Bohm's theory, but *any* theory purporting to supplement the quantum mechanical

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[5] One of the premises of von Neumann's proof has been shown to be physically untenable (Bell [1966]), the proof being therefore irrelevant. But sound proofs to the same effect were latter discovered (Gleason [1957], Bell [1966], Kochen and Specker [1967], Mermin [1990]). Retrospectively, thus, we know that the implementation of a HVT *had* to have a price.

value assignment *has* to be non-local, if it is to coincide with QM in certain specific statistical predictions about EPR-type systems (Bell [1964]). These predictions have subsequently been confirmed by a series of experiments, the most important of which being performed in the early 1980's by Alain Aspect and his team (Aspect *et al*. [1982]).

There is, however, an important conceptual difference between the form of non-locality present in Bohm's theory – or in any HVT, as Bell's theorem shows – and that associated with the quantum-mechanically entangled states. According to QM, when two otherwise independent objects become entangled some of their ontological independence disappears, so to speak, since the theory precludes the ascription of certain properties to one regardless of the other. When an action on one object breaks the entanglement, the new state of the system instantaneously attributes a new set of properties to the remote object. To be more precise, it is *not* that certain well-defined values of certain magnitudes belonging to the object *change*, but that previously undefined values *become definite*. It can be proved that this kind of influence is entirely uncontrollable: we cannot capitalize on it to send a signal from one branch of the experiment to the other.

In Bohm's HVT theory, on the other hand, the objects are considered as possessing a complete set of well-defined, ontologically independent properties all the time. But these properties can undergo instantaneous changes due to actions on the remote member of the pair. Such non-local influences are mediated by physical forces of non-classical origin, the "quantum forces". These forces are *in principle* controllable (on the assumption – thus far unsubstantiated – that the hidden variables are controllable). On a realist construal of the theory, this interaction means that there is a kind of pervasive interconnectedness in the world. The common opinion that the worldview established by Bohm's theory is "holistic" is based on this fact.

But we think that this opinion is open to criticism. Although in Bohm's theory the objects are connected in a non-classical way, through a new force field, their ontological independence is preserved all the time. It is in QM that this independence is sometimes violated, as we have emphasized. Another way of seeing the point is to remark that it is QM, *not* Bohm's theory, that imposes limits on the theoretical analysability of certain objects. According to the latter, the objects and their properties are always conceptually analysable. The fact that in certain cases these properties may undergo instantaneous changes as a result of remote actions does not seem to justify the usual claim that it introduces a “holistic” worldview.[6]

Notice, incidentally, that in his original article Bohm himself pointed out that his theory differs from QM by preserving the classical ideal of complete analysability.[7] It was only later that he began to insist that his theory introduces a kind of “wholeness”, endeavouring to apply this idea outside its original area (see e.g. Bohm [1983], [1987]).

In their review of the development of Bohm’s ideas, Hiley and Peat [1987] remark that there is indeed a widespread belief that Bohm’s proposal in 1952 “is totally against the spirit of his later work on the implicate order”. The present article contributes to justify this belief. But the authors argue that, to the contrary, “the quantum potential also contained a notion of wholeness, even though analysis was still possible” (p. 11). If holism is characterised as in section 1, above, this assertion would have a paradoxical ring to it. This seems to indicate that Hiley’s and Peat’s notion of holism does not coincide with ours. Upon closer inspection, however, the difference appears to lie in their notion of *analysis* itself, since they endeavour to base their claim exactly on the fact that Bohm’s HVT is *non-local*, and that locality “is a necessary condition if the notion of analysis of a system into separately and independent[ly] existent constituent parts is to be carried out” (p. 15). But now this is in conflict with their assertion on p. 11, just quoted, and with Bohm’s own remark in 1952 that his theory rescues analysis from the threat of QM. Interestingly, this point seems to have been entirely lost of sight in Bohm’s late writings. It should however be conceded that Bohm and his collaborators have drawn attention to an aspect that deserves further analysis: since the wavefunction, and therefore the quantum potential, depends on the system as a whole, the *relationship* between two (or more) particles depends on something going beyond what can be described in terms of these particles alone (Bohm [1987], pp. 37-8, Hiley and Peat [1987], p. 15). Whether we

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[6] Esfeld [2000] also understands quantum entanglement as introducing holism into, and hidden variables as eliminating it from microphysics (see section 4 and pp.62-3).

[7] On p. 188, for instance, commenting on Bohr’s holism, he remarks: “We differ from Bohr, however, in that we have proposed a method by which the role of the apparatus can be analyzed and described in principle in a precise way, whereas Bohr asserts that a precise conception of the details of the measurement process is as a matter of principle unattainable.” And in the conclusion of the paper he notices that his theory is congenial to a realist/analytic interpretation, according to which “the world as a whole is objectively real, and that, as far as we now know, it can correctly be regarded as having a precisely describable and analyzable structure of unlimited complexity” (p. 189).

should follow these authors and broaden the notion of holism to count this aspect as holistic is, of course, largely a matter of taste.

6. CONCLUSIONS

In this work we identified three forms of holism associated with theories of microphysics: quantum mechanical, Bohm's, and Bohr's holism. We shall now try to briefly sketch the implications of each of them to the issue of holism, in both the epistemological and the ontological versions (in our sense, not Shimony's).

We offered several reasons for considering Bohr's holism as hardly possessing more than historical interest: 1) It is not an essential element of any physical theory, but simply part of a very particular interpretation of QM; 2) it does not derive from any independent philosophical theory, nor forms a coherent philosophical theory of its own; 3) it has been purposely devised to evade one specific argument for the incompleteness of QM, being thus ad hoc; and, finally, 4) it is entirely ineffective against a modified version of that argument. It is thus pointless to try to see what consequences Bohr's holism may have to the general validity of the method of analysis and to the issue of the holistic character of the world itself.

Concerning Bohm's holism, we argued that although Bohm's HVT does indeed exhibit a very peculiar non-classical aspect, non-locality, this does not justify calling the theory "holistic". It is true that if the theory is taken as reflecting faithfully reality, the world would be much more "connected" than the world of classical physics, in the sense that many of its objects would be linked by an additional force field, extending without attenuation and instantaneously to arbitrarily remote regions of space, and reflecting the relevant parts of the environment. But the ontological independence of these objects would be preserved all the time.

Thanks to Bell's theorem and the associated experiments, we know that unpalatable nonlocality will be present in any other consistent, empirically adequate HVT. But there is, of course, at least one option at our disposal: to take QM as it is, without any complementary variables. We would, then, have a genuine case of holism, namely, holism associated with quantum entanglement. This represents an unequivocal limitation of the method of analysis.

If now we refrain from adopting an instrumentalist, or any other anti-realist interpretation of the theory, quantum holism should be taken as a theoretical counterpart of the real world.[8] This conclusion depends, of course, on the further assumption that QM has come to stay, or at least that its peculiar way of ascribing properties to objects will be inherited by any theory that may eventually supersede it. The fact that this assumption is, and will always be, open to doubt should not lead us to underrate the strong evidence it presently has in its favour, given the unfailing predictive success of QM and the severe constraints posed on alternative theories by Bell's and Aspect's results and by the mathematical proofs mentioned in footnote 5. We are, thus, at least partly justified in believing that there is some holism in the world, according to contemporary physics.

But a wide gulf separates this tentative conclusion from the usual assertions found in unspecialised literature concerning holism in quantum physics. Bohm is often taken as a source of inspiration for the current wave of holism. But we should underline that his HVT does not provide adequate support for holism, as defined in section 1. At present, QM provides the only instance of holism in microphysics. It is unlikely, however, that quantum entanglement – for which there is indeed overwhelming experimental evidence – can be as pervasive and enduring as required to underpin the claim that rocks, seas, plants, animals, stars, galaxies, men, minds are all quantum-mechanically entangled, forming therefore a single whole (unless we take this as meaning simply the trivial and old truth that these things somewhat interact). Although our present theoretical understanding of the conditions leading to the dissolution of entanglement is still rudimentary, it is quite certain that this kind of quantum state is extremely fragile and peculiar, being almost impossible to obtain in macroscopic bodies.[9]

The strong thesis of the *general* failure of the method of analysis in quantum physics, and the fashionable association of quantum physics with mystical holistic approaches seem, therefore, to be groundless. We have not, *a fortiori*, any solid scientific or philosophical basis

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[8] For a critical assessment of the orthodox opinion that quantum physics provides evidence against scientific realism, see Chibeni [1999].

[9] This assertion is rather sensitive to the stand taken regarding the controversial issue of the interpretation of QM. We lack space to give further details here. Esfeld [2000], section 4, presents an interesting case against the thesis of "universal quantum holism".

for inferring that the world itself and at large is a single un-analysable whole, or for accepting any other sweeping, unspecific metaphysical statement of ontological holism.[10]

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OLISMO IN MICROFISICA

Riassunto

Il concetto di olismo sembra aver raggiunto la sua attuale popolarità negli ambienti intellettuali soprattutto in seguito ad alcuni sviluppi della fisica del ventesimo secolo. Lo scopo di questo articolo è identificare e discutere brevemente questi sviluppi e il loro preciso contributo alla questione dell'olismo. Nell'Introduzione l'olismo viene caratterizzato come il fallimento, nell'ambito di un data cornice teoretica, del cosiddetto metodo dell'analisi, stando al quale gli oggetti possono essere trattati come concettualmente divisibili in parti ontologicamente indipendenti. Nel secondo paragrafo è spiegato come la questione dell'olismo sorga nell'ambito della meccanica quantistica. In particolare, viene mostrato come questo problema sia collegato con la lunga controversia sulla completezza della descrizione della realtà fornita dalla teoria dei quanti. Il paragrafo 3 è dedicato all'esame del più semplice tipo di sistemi della meccanica quantistica che evidenziano l'olismo, vale a dire le coppie di oggetti correlati studiati per la prima volta da Einstein, Podolsky e Rosen (EPR) nel loro famoso articolo del 1935. Viene mostrato nei particolari perché, e in che senso, questi oggetti formino un singolo inanalizzabile "tutto". Mediante un semplice esempio viene illustrato il contrasto tra questa singolare descrizione teorica e quelle tipiche delle teorie classiche. Nel paragrafo 4 è analizzata una forma diversa di olismo, che fu introdotta da Niels Bohr durante la sua difesa della completezza della meccanica quantistica. Si sostiene che questa forma di olismo non deriva dall'olismo della meccanica quantistica esibito, ad esempio, dai sistemi EPR. Si sostiene inoltre che, nonostante la sua notevole influenza storica, l'olismo di Bohr presenti parecchie imperfezioni concettuali. Infine, il paragrafo 5 esamina la forma di olismo associata con la teoria delle variabili nascoste di David Bohm. Si mostra che, sebbene questa teoria e, in generale, una qualsiasi teoria delle variabili nascoste, presentino molti strani aspetti non classici, l'olismo, contrariamente a quanto viene comunemente accettato nella letteratura, *non* è tra essi. In particolare viene sottolineata la distinzione e l'indipendenza tra la non-località e l'olismo. Nella Conclusione si sottolinea che nessuna delle forme di olismo microfisico identificate in questo articolo sembra supportare le generiche asserzioni sull'olismo che si incontrano di frequente nella letteratura non specialistica, secondo le quali il mondo, in grande, costituisca un singolo, indivisibile tutto.