Holism in Cartesianism and in Today's Philosophy of Physics

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SUMMARY

The aim of this paper is to contribute to a more balanced judgement than the widespread impression that the changes which are called for in today's philosophy of physics and which centre around the concept of holism amount to a rupture with the framework of Cartesian philosophy of physics. I argue that this framework includes a sort of holism: As a result of the identification of matter with space, any physical property can be instantiated only if there is the whole of matter. Relating this holism to general relativity, I maintain that this holism cannot be directly applied to today's philosophy of physics consequent upon the failure of geometrodynamics. I show in what respect precisely the holism in quantum physics amounts to a revision of the holism within Cartesianism.

Key-words: holism, Cartesianism, geometrodynamics, quantum entanglement, non-separability

1. INTRODUCTION

This paper proposes three theses:[1]

1) In contrast to widespread beliefs which regard Descartes' philosophy of physics solely as the source of the modern mechanistic view of nature, Cartesian philosophy of physics admits of a substantial holism.
2) This holism can be applied to general relativity. However, the programme of a further development of general relativity along the lines of this holism failed for physical reasons.
3) When it comes to holism in today's philosophy of physics, we have to go into quantum theory. Quantum holism is different from the sort of holism that Cartesian philosophy of physics admits. Nonetheless, comparing quantum holism with the holism in Cartesian philosophy of physics enables us to reach a more balanced judgement than the [18] widespread impression that quantum holism amounts to a rupture with the Cartesian tradition in the philosophy of physics.

That sort of holism which Cartesian philosophy of physics admits is a consequence of the identification of matter with space. To start, I therefore go briefly into the evidence for such an identification in Descartes' as well as Spinoza's texts. However, my point is not to enquire whether there is conclusive evidence for attributing such an identification to Descartes or Spinoza themselves. The only point I need is that the philosophical framework which Descartes and Spinoza lay out for physics admits of an identification of matter with space

1 I am grateful to Peter McLaughlin for helpful comments and improvements to my English.

(section 2). I then give a systematic sketch of the ensuing holism which I call “holism of matter as holism of space” (section 3).

Is this holism relevant to today’s philosophy of physics? It is suggestive to try this holism out on general relativity. There is a programme for a further development of general relativity which amounts to a concrete elaboration of this holism, namely the geometrodynamics of John Wheeler. However, this programme failed for physical reasons. I therefore argue that holism of space cannot be directly applied to current philosophy of physics. We cannot avoid a profound revision of the Cartesian framework in today’s philosophy of physics (section 4).

In the last part of the paper, I go into that area of today’s physics where there is convincing evidence for some sort of a holism, namely quantum theory. My aim is to employ the holism that Cartesian philosophy of physics includes in order to work out in what respect precisely quantum holism departs from the tradition that dominated modern philosophy of physics. My thesis is that starting from the holism in Cartesianism, the changes which are called for today amount to a conceptual revision of what holism in physics consists in (section 5).

2. THE IDENTIFICATION OF MATTER WITH SPACE IN CARTESIANISM

Descartes counts among the first who have elaborated on a philosophy of nature along the lines of modern science. Descartes rejects what he takes to be the Aristotelian philosophy of nature. According to him, there is no specific form for each kind of things which constitutes the essence of each member of a kind and which is imperishable. Instead, all physical things are characterized merely by the attribute of extension. By extension, Descartes means spatial extension, i.e., extension in length, breadth, and depth, whereby he considers space to be Euclidean. The terms “corporeal”, [19] “material”, and “extended” are identical in meaning and reference (*Principles*, part II, § 4). Descartes not only renounces Aristotelianism, but also the ontology of atomism. He maintains that there are no smallest, indivisible bodies. Every corporeal thing can in principle be divided (*ibid.*, §§ 20, 34).

Nonetheless, Descartes agrees with the Aristotelists as well as the atomists that change is possible only if there is something which persists throughout all changes. Since every body is divisible, there is no corporeal shape which cannot fade away. Consequently, for Descartes, that which necessarily persists throughout all changes can only be the corporeal realm as a whole irrespective of corporeal shapes. In the *Synopsis of the Meditations*, Descartes says:

> First, we need to know that absolutely all substances … are by their nature incorruptible and cannot ever cease to exist … Secondly, we need to recognize that body, taken in the general sense, is a substance [*corpus quidem, in genere sumptum, esse substantiam*] so that it too never perishes. But the human body, in so far as it differs from other bodies, … can very easily perish.[2]

This passage supports the following interpretation: No substance can cease to exist. But every particular body, such as a human body, can cease to exist. Therefore, only the corporeal realm taken as a whole is a substance. There is no multitude of corporeal substances. All corporeal things are just one substance. As mentioned above, Descartes considers the terms “corporeal”,

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[2] *Synopsis of the Meditations* (Descartes, 1965–1973, vol. 7, pp. 13–14). Translation adopted from Cottingham, Stoothoff & Murdoch, 1984–1991, vol. 2, p. 10. See furthermore *Principles*, part II, § 4, and letter 266 to Regius, Jan. 1642 (Descartes, 1965–1973, vol. 3, p. 505).

"material", and "extended" to be synonymous. Furthermore, he maintains that extended substance and physical space are identical (*Principles*, part II, §§ 10–12). If we base ourselves on the quoted passage from the *Synopsis of the Meditations*, the conclusion which suggests itself is that the corporeal substance is the same thing as space.[3]

However, Descartes' position is ambiguous: On the one hand, the argument that no substance can cease to exist leads him to conceive the whole corporeal realm as one substance. On the other hand, in the first part of the *Principles*, § 60, Descartes assumes that the parts of the corporeal substance are themselves substances: he maintains that there is a real distinction between the parts of the corporeal substance; a real distinction is the sort of distinction that applies to substances.

Let us briefly consider some more textual evidence for an identification of matter with space in Cartesianism by going into Spinoza's philosophy of physics. Spinoza remarkably changes Descartes' metaphysics: he acknowledges only one substance which is identical with God and nature. Extension is one of the attributes of the substance. Nonetheless, in his [20] philosophy of physics, Spinoza can be seen as following the line of thought which Descartes sets out in the quoted passage from the *Synopsis of the Meditations*. The terms "corporeal", "material", and "extended" are identical in meaning and reference.[4] Like Descartes, Spinoza is opposed to the ontology of atomism.[5] But he also maintains that every change requires something which persists throughout all changes.

Spinoza presented his theory of extension mainly in the scholium to the fifteenth proposition of part one of the *Ethics*. Adopting Descartes' terminology, he speaks of the one substance, insofar as it is extended, as corporeal or extended substance (or simply as quantity or matter). In two places in that scholium, he claims that this substance can only be conceived as infinite, unique, and indivisible.[6] Thereby he does not intend to deny that every body is divisible. In the first place, he adds the following example:

> So also others, after they feign that a line is composed of points, know how to invent many arguments, by which they show that a line cannot be divided to infinity. And indeed it is no less absurd to assert that corporeal substance is composed of bodies, *or* parts, than that a body is composed of surfaces, the surfaces of lines, and the lines, finally, of points.[7]

According to this quotation, the corporeal substance is a continuum. Every division results in something which can be divided still further. The indivisibility of the substance, which goes with the divisibility of all corporeal things, can be conceived in the same way as the

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[3] See, for instance, Hesse, 1961, p. 103; Hartz, 1989, pp. 23–24. For an argument against this interpretation, see Woolhouse, 1994, in particular pp. 30–33.

[4] See especially *Ethics*, part I, proposition 15 scholium (Spinoza, 1925, vol. 2, p. 57, ll. 13–14); *Ethics*, part II, definition 1; *Descartes' Principles Demonstrated in Geometrical Manner*, part II, proposition 2 and corollary. Compare Lecrivain, 1986, pp. 34–39.

[5] Compare *Descartes' Principles Demonstrated in Geometrical Manner*, part II, proposition 5 with *Ethics*, part I, proposition 15 scholium (Spinoza, 1925, vol. 2, p. 59, l. 35 – p. 60, l. 5) (water example) and letter 6 to Oldenburg (Spinoza, 1925, vol. 4, p. 29, ll. 12–17). As to Spinoza's rejection of atomism, see Rice, 1975, pp. 200–201; Lecrivain, 1986, pp. 37–38.

[6] Spinoza, 1925, vol. 2, p. 58, l. 34 – p. 59, l. 1 and p. 59, ll. 29–30.

[7] Spinoza, 1925, vol. 2, p. 59, ll. 3–9. Translation adopted from Curley, 1985, p. 423. See furthermore letter 12 to Meyer, 20 April 1663 (Spinoza, 1925, vol. 4, p. 55, l. 11 – p. 56, l. 4).

indivisibility of a three-dimensional spatial continuum: focusing on the continuum, divisions are nothing but demarcations within the continuum. Spinoza writes in a letter: “If one part of matter were reduced to nothing, the whole extension would vanish instantly.”[8] Thus, parts of matter can only exist within the whole of matter, i.e., the whole of extension.

Spinoza explicitly identifies extension and body with space only in his reconstruction of Descartes’ Principles.[9] This writing is not an expresssion of Spinoza’s own position in the first place.[10] Nonetheless, one can argue that Spinoza regards the corporeal substance as being identical with space. The scholium to the fifteenth proposition of part one of the “Ethics” supports such a reading.

Bennett, 1988, ch. 4, develops an interpretation according to which Spinoza identifies the physical realm with space. He coins the term “field metaphysic” for Spinoza’s philosophy of the extended world.[11] He traces the talk of bodies in space back to properties which are predicated of regions of space. Bennett does not use the word “holism”. He only speaks of [21] monism. He sums up his interpretation in these terms:

> It suggests that there is just one substance—namely, the whole of space—regions of which get various qualities such as impenetrability, mass, and so on, so that any proposition asserting the existence of a body reduces to one saying something about a region of space (§ 22.1).

Hence, all propositions which refer to things in space are reduced to propositions which refer to regions of space and which attribute physical properties to these regions.

The obvious problem for ascribing an identification of the corporeal substance with space to Descartes and Spinoza is that their physics is formulated in terms of moving bodies and, in particular, laws of the conservation of motion in the whole universe.[12] Identifying matter with space, by contrast, implies that physics can be reconstructed without being committed to material things in addition to space. Furthermore, regions of space may have physical properties; but they cannot move. However, I propose to postpone this problem to the second half of the next section. What I intend to do next is to consider the identification of the corporeal substance with space as a basis upon which a holism in the philosophy of physics can be built. The possibility of an identification of matter with space is the only point which I take up from Descartes’ and Spinoza’s philosophy of physics. Because there is evidence for such an identification in some of Descartes’ and Spinoza’s texts, I claim that the position which I will sketch out is a holism within the framework of Cartesian philosophy of physics.

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8 Letter 4 to Oldenburg (Spinoza, 1925, vol. 4, p. 14, l. 19–20). See furthermore *Short Treatise on God, Man, and His Well-Being*, part I, ch. 2, § 20 (Spinoza, 1925, vol. 1, p. 25, l. 19 – p. 26, l. 6).

9 *Descartes’ Principles Demonstrated in Geometrical Manner*, part II, definition 6 as well as proposition 2, corollary and demonstration.

10 But the reference in *Ethics*, part I, proposition 15 scholium (Spinoza, 1925, vol. 2, p. 59, ll. 16–17) (elaboration of the claim that there is no empty space) is apparently meant to be a reference to *Descartes’ Principles Demonstrated in Geometrical Manner*, part II, proposition 3.

11 For a criticism of Bennett’s interpretation, see, for instance, Curley, 1991. As to a criticism of the identification of matter with space in the context of the relation of Spinoza’s philosophy of physics to today’s philosophy of physics, see Paty, 1986, p. 269, and van Zandt, 1986, p. 258.

12 As to Descartes, see *Principles*, part II, §§ 36–42. As to Spinoza, see letter 32 to Oldenburg, 10 Nov. 1665 (Spinoza, 1925, vol. 4, p. 172, l. 15 – p. 173, l. 5). See furthermore *Ethics*, part II, proposition 13, lemma 3, corollary.

Nonetheless, my point is not to enquire whether that holism can be attributed to Descartes or to Spinoza himself.

3. HOLISM OF MATTER AS HOLISM OF SPACE

That sort of holism which Cartesian philosophy of physics includes is based upon identifying matter with physical space, whereby physical space is conceived as a three-dimensional, Euclidean space. If there are parts of space, regions count among the parts of space. Regions are, like space itself, three-dimensional. Regions can be arbitrarily small. Furthermore, one can maintain that dimensionless points are also parts of space. Many of our physical theories are formulated in such a way that physical properties are regarded as being instantiated at points of space or space–time. However, in metaphysics, it is in dispute whether one should admit points as parts of space and approve of a realism about points.[13] Therefore, I [22] formulate holism of space without endorsing a commitment to points as parts of space. If there are points, holism of space, of course, applies to points of space as well as regions of space.

According to the conception under consideration, physical space is a continuum. Whatever account of space as a continuum one accepts, if there are proper parts of space such as regions or points, there cannot be only one thing which has the property of being a point or a region of space. Something can have the property of being a point or a region of space only if there are other points or regions which run through the whole space. What makes something a point or a region of space is relational properties or relations to other points or regions within the whole of space if space is a continuum. As soon as one refers to one point or region of space, one has to recognize the existence of other points or regions which extend as far as the whole space.

It may be regarded as trivial that something can have the property of being a point or a region of space only if there are other points or regions which run through the whole space. However, this issue turns into an interesting holism of the physical realm as soon as we identify matter with space. Identifying matter with space does not amount to the elimination of matter. It only amounts to the claim that there are no physical systems such as particles or fields in addition to space. Matter and space are the same thing. The points or regions of space are the parts of matter. They are not only the basic individuals, but also the sole individuals in the physical realm. They have physical properties, and all physical properties can be reduced to properties of points or regions of space.

If the points or regions of space are the things that have physical properties, there cannot be only one thing which has physical properties, because there cannot be only one thing which has the property of being a point or a region of space. Consequently, any physical property can only be instantiated if there are a number of material things—points or regions of space which extend as far as the whole physical realm. Therefore, this position is a holism of matter. One can say that all matter is one holistic system. For space, in turn, the identification with matter means that it is matter everywhere. Every part of space is a part of matter. There is not even a conceptual distinction between space and matter. It is therefore not possible to

13 For an argument that points are limits of extended parts of space and not parts of space themselves, see Hoffman & Rosenkrantz, 1994, pp. 100–113, 188–193.

reconstruct this position by starting with some sort of an empty space and then imagine instantiations of physical properties being inserted in that space. Hence, it is necessary that if something is a part of space, it instantiates physical properties of some sort. Some physical properties can be attributed to every point and every region of space. In this sense, there is no empty space.

[23] Consequently, strictly speaking, every physical property is relational. That a point or a region of space has a physical property is relative to there being other points or regions of space which also have some physical properties. However, this conception alone does not contain any connections between specific property instantiations: it merely says that something can instantiate physical properties only if there are other things which have some physical properties as well and which extend as far as the whole material realm; but it does not impose any restrictions upon these other physical properties. Such restrictions are due to causal relations.

It could still be objected that this holism is somewhat trivial: regarding physical properties as properties of regions of space trivially has the consequence that any physical property can only be instantiated if there are many regions of space which run through the whole space. However, this objection overlooks the fact that the identification of matter with space does not leave space untouched, so to speak. As soon as space is considered to be the same thing as matter and different physical properties are regarded as being instantiated by its points and regions, it is seen as having an internal structure. This structure consists in the different physical properties (or the different values of these properties) which space has in different regions, i.e., different parts. The regions may even have rather sharp boundaries; in any case, there are vague boundaries which delimit regions. Conceiving matter and space as the same thing thus has two consequences:

- Identifying space with matter yields an internal structure of space in the sense of parts of space with different physical properties.
- Identifying matter with space ties the instantiation of all physical properties to the instantiation of the properties which make something a part of space. Consequently, any physical property can only be instantiated if there is the whole physical realm.

It is thus both the instantiation of physical properties by regions of space and the dependence of something insofar as it is a region of space on there being other regions together with which it encompasses the whole space that turns space–matter into a holistic system. I propose to call this philosophy of physics “holism of matter as holism of space” (or just “holism of space”):

Holism of matter as holism of space

> Matter and the continuum of physical, three-dimensional, Euclidean space are the same thing. The parts of matter are identical with the points or regions of space. There are no physical systems such as particles or fields in addition to space. All physical properties are properties of points or regions of space. Something can be a point or a region of space only if there are other points or regions together with which that thing encompasses the whole space. Since the instantiation of any physical property [24] is tied to the instantiation of the properties which make something a part of space, every

> physical property can only be instantiated if there is the whole of matter, i.e., the whole of space.

According to holism of space, there is an absolute space. But this space is identical with matter. This position can therefore not be associated with the theory of an absolute space as an entity in distinction from matter. Objections against such a theory of space do not touch holism of space.

To conclude the exposition of holism of space, let us briefly consider whether this position can take motion into account. Points or regions of space cannot move. But they can undergo a change of their physical properties. We can reconstruct the talk of bodies that move in space by assuming a coordinated change of physical properties of neighbouring regions of space: one region of space looses a certain physical property—it changes from being *F* into being *non-F*. Immediately afterwards, a region in the immediate neighbourhood of the first region acquires that property—it changes from being *non-F* into being *F*, and so on. We thus arrive at a spatio–temporally continuous set of place–times which are similar as far as their physical properties are concerned and which are distinguished from their environment as a result of this similarity. On the basis of such a spatio–temporally continuous set of place–times, we can reconstruct the talk of a motion of a body through space. Bennett, 1988, § 22.2–3, proposes such an explanation of motion in his interpretation of Spinoza's philosophy of physics. Clifford, 1876, and Broad, 1933, p. 158, already consider such an account of motion. I therefore conclude that it is possible to reconstruct the talk of the motion of bodies in space on the basis of holism of space. The internal structure of space which consists in regions that are distinguished from one another by their physical properties makes such a reconstruction possible. Let me, however, emphasize that it is not my intention to attribute this account of motion to Descartes or Spinoza.

4. HOLISM OF SPACE AND GENERAL RELATIVITY

Does the holism which Cartesian philosophy of physics admits have any relevance to today's philosophy of physics? Is holism of space a viable option today? When it comes to examining whether holism of space fits into current physics, it is general relativity on which we have to focus. If holism of space is applicable to the interpretation of general relativity, then general relativity admits of a substantial holism. Since space and time are united in relativity physics, holism of space has to be changed into holism of space–time in order to be applicable to the philosophy of [25] relativity physics. We have to replace the continuum of physical, three-dimensional Euclidean space that Descartes and Spinoza conceive with the notion of a continuum of physical, four-dimensional space–time which has the structure of a Riemannian manifold, i.e., which is curved. However, this change is nothing but an adaptation of holism of space to the contemporary state of science.

At first glance, it could seem that the identification of matter with space–time is a direct consequence of physical field theories. These theories are often described in such a way that the field properties are predicated of space–time points. Hence, it could seem that the field properties are properties of space–time points. However, a physical field theory states merely that the field has the properties in question *at* space–time points, but not that these are properties *of* space–time points. Therefore, holism of space–time cannot be based upon field theories alone. It depends on an argument which establishes that these theories do not require an ontological commitment to physical systems (such as fields) in addition to space–time (compare Graves, 1971, pp. 316–317). Teller, 1991, p. 382, maintains that, given physical field theories, we also have the option to start with fields and to construct a relational theory of space–time on the basis of an ontology of fields (see also Auyang, 1995, § 20).

Nonetheless, there is a direct application of holism of space–time to general relativity, namely the programme of *geometrodynamics.* This programme was introduced by Wheeler some forty years ago. Geometrodynamics gives a concrete physical shape to holism of space–time. It is the only programme which sets out to construct physics in such a way that no ontological commitment to physical systems in addition to space–time is required.[14] Whereas in general relativity only the theory of gravitation can be built on a geometrical description of space–time, geometrodynamics envisages constructing electromagnetism and elementary particle physics solely on the basis of a geometrical description of empty curved space–time. Empty space–time means in this context a space–time without additional physical systems. Wheeler (1962b) writes:

> Is space-time only an arena within which fields and particles move about as “physical” and “foreign” entities? Or is the four-dimensional continuum all there is? Is curved empty geometry a kind of magic building material out of which everything in the physical world is made: (1) slow curvature in one region of space describes a gravitational field; (2) a rippled geometry with a different type of curvature somewhere else describes an electromagnetic field; (3) a knotted-up region of high curvature describes a concentration of charge and mass-energy that moves like a particle? Are fields and particles foreign entities immersed *in* geometry, or are they nothing *but* geometry? (p. 361)

[26] The theory of space–time which treats physical properties thus consists in a description of the geometrical properties of space–time such as its curvature. The ontological claim of geometrodynamics is that the physical realm is identical with the four-dimensional space–time continuum with its geometrical—i.e., physical—properties. Geometrodynamics therefore is often connected with Cartesianism and Spinoza’s theory of the physical realm in particular (Graves, 1971, pp. 79–101; Campbell, 1976, pp. 100–104; Mathews, 1989, pp. 5–6). It can be seen as the attempt to work out the identification of matter with space in today’s physics.

However, geometrodynamics failed. The problems with which it could not cope are mainly the following three ones:

- *initial value*: it has been shown by means of counterexamples that the geometrical description which geometrodynamics offered could not distinguish between some physically different initial conditions in electromagnetism (see Misner, 1974, pp. 12–14).
- *singularities*: geometrodynamics intended to avoid singularities (Wheeler, 1962a, in particular pp. 25–31, 45–66). However, that attempt failed. Geometrodynamics could not elude singularities. Singularities require that physical systems such as particles are acknowledged in addition to space–time, since the equations of the relevant field, which is supposed to indicate physical properties of space–time, do not apply at those points where the singularities occur (see Stachel, 1974, pp. 33–39).

[14] See Wheeler, 1962a, in particular pp. XI–XII, 8–87, 129–130, 225–236. For an overview, see Wheeler, 1962b. See furthermore Graves, 1971, chs. 4–5, in particular pp. 236, 312–318. Clifford, 1876, can be considered as a precursor of Wheeler’s programme.

- *elementary particles*: fermions, i.e., elementary systems of spin 1/2 such as electrons, could not be treated by geometrodynamics. That is to say: geometrodynamics failed to give an account of elementary particles (see Stachel, 1974, pp. 45–46).

The first two problems concern already classical geometrodynamics, i.e., the attempt to unite gravitation with electromagnetism on the basis of an ontology of space–time without additional physical systems. The third problem concerns quantum geometrodynamics, i.e., the attempt to include quantum elementary particle physics in geometrodynamics. Especially as a result of the third problem, Misner, Thorne and Wheeler, 1973, § 44.3–4, repudiated geometrodynamics in the sense of a programme which sets out to build physics solely on space–time without acknowledging additional physical systems.

On the one hand, a metaphysics such as holism of space or space–time is not tied to the fate of one specific programme in physics. In particular, holism of space or space–time is not committed to regarding the physical [27] properties of space or space–time as geometrical properties. On the other hand, if such a metaphysics is to be more than a mere philosophical speculation, it has to be able to spell out in concrete terms how a reduction of all physical properties to properties of points or regions of space–time can be carried out. If such a metaphysics is to succeed in the philosophy of physics, it has to show in concrete terms how a reconstruction of our physical theories is possible without being committed to physical systems in addition to space–time. However, we do not have a physics at our disposal that is not committed to physical systems over and above space–time, and such a physics is not in prospect as a further development of current physics either, since the programme of such a further development failed.

5. HOLISM IN CARTESIANISM AND QUANTUM HOLISM

The argument of the last section shows: Holism of space or space–time is not a viable option in today’s philosophy of physics. It is not plausible to connect general relativity with a substantial holism of matter. Consequently, even if we lay stress on the fact that Cartesian physics admits of a sort of holism, there is no prospect of circumventing a revision of Cartesianism in current philosophy of physics.

However, my point is: Holism of space has an indirect relevance to today’s philosophy of physics. If we approach the framework which Descartes laid out for physics with hermeneutic good-will, we have to acknowledge that this framework admits of a substantial holism. Because of this holism, the changes which are called for in today’s philosophy of physics and which centre around the concept of holism do not constitute a simple rejection, but a revision of Cartesianism in the philosophy of physics. Starting from the holism in Cartesianism, these changes amount to a conceptual revision of what holism in physics consists in. I intend to argue for this thesis now by going into that area of contemporary physics where there is convincing evidence for some sort of a holism, namely quantum physics. (As regards a general conception of holism which can serve as a basis for a comparison between different sorts of holism, I have developed a proposal in Esfeld, 1998).

Why do people speak of holism with respect to quantum physics? The states of two or more quantum systems can be in superposition with each other. Consider the simplest example (Bohm, 1951, pp. 611–622): Spin is a physical property which is treated only in quantum theory. There are systems of spin 1/2 such as electrons and neutrons. In this case, the spin in any of the three orthogonal spatial directions can take only two definite numerical values. Call these values "spin up" and "spin down". Imagine that [28] two systems of spin 1/2 are emitted together from a source. After the emission, their interaction ends, because they fly apart in opposite directions. Nonetheless, however far apart in space these two systems are removed, the spin state of the whole, i.e., the joint spin state of these two systems taken together, is a superposition of the first system having spin up and the second system having spin down with the first system having spin down and the second system having spin up in any direction. This state is known as the *singlet state*.

The important point is that neither of the two systems is in a state of either spin up or spin down in any direction. Consequently, neither system has a definite numerical value of any local spin observable. A *local observable* is an observable that relates only to one of the two systems. Spin in z-direction of the one system and spin in z-direction of the other system are examples of local observables. Only the whole, which consists of these two systems, has a definite numerical value of a global spin observable, namely the total spin. A *global observable* is an observable that relates to the whole.

Assume that we measure the spin of one of two such systems in an arbitrary direction. Given the direction measured and the outcome of this measurement, the probability for the outcome of a spin measurement on the other system is changed (unless the spin is measured on both systems in orthogonal directions). As regards a spin measurement on the other system in the same direction, it is even possible to predict the outcome with certainty, i.e., either "spin up" or "spin down" has probability one. These correlations are well confirmed by experiments—even by experiments which carry out measurements on two such systems at a space-like distance. (The first such experiment is Aspect et al., 1982). The famous theorem of Bell, 1964, says, to put it in a nutshell, that there is no explanation of these correlations within the ontology of classical physics. In particular, the emission of the two systems from the source cannot be a common cause that accounts for these correlations.

The state of a system at a given point of time determines the probability distributions of those properties or observables of the system whose value can change during the existence of the system. Position, momentum, and spin in a given direction count among these properties. These properties can be referred to as the *state-dependent properties*. By contrast, properties such as mass and charge are state-independent; their value does not change during the existence of the system.

Following Schrödinger, 1935, p. 555, cases such as the singlet state are known as *entanglement*. In the case of entanglement, the states of two or more systems are entangled in such a way that only the whole, i.e., [29] these systems taken together, is in what is known as a *pure state*. In the example mentioned, only the whole has a definite numerical value of a spin observable, namely the total spin; but neither of the two systems is in a state in which it has a definite numerical value of a spin observable in any direction. Nonetheless, it is possible to give a description of each of these systems in the formalism of quantum theory. This is a description in terms of a so-called mixed state in the sense of what is known as an *improper mixture* (d'Espagnat, 1971, ch. 6.3). The term "improper mixture" is misleading: an improper mixture is not a mixture at all. "Improper mixture" is the name of a description that in the case of entanglement of the states of two or more systems contains all the information that is available about each of these systems considered independently of the other systems.

In the example of the singlet state above mentioned, the description in terms of an improper mixture contains the probability distributions for a measurement of all the local spin observables of each of the two systems. But this description ignores the correlations between the possible values of these observables which can be acquired in measurement. It does not include the information that if the one system acquires the value spin up in a certain direction, the value of the spin which the other system acquires in the same direction is spin down. This description always indicates probability 0.5 for spin up and probability 0.5 for spin down in any direction for each of the systems as the outcome of a measurement, independently of whether or not a measurement on the other system has been carried out. The description in terms of a mixed state is identical for the two systems.

Consequently, *in the case of entanglement, the description which relates to each of the systems in question does not completely determine the local observables of this system*; for this description does not contain the change in the probability distributions of local observables of this system consequent upon a measurement of another system to which entanglement extends. Furthermore, this description does not determine the state of the whole, i.e., the state of these systems taken together. It is therefore possible that two systems can be described in terms of the same mixed states as in the mentioned case without being in the singlet state. Hence, *in the case of entanglement, it is only the description of the whole in terms of a pure state*, such as the singlet state, *which completely determines the local properties of the parts and their relations* (to the extent that these properties and relations are determined at all in quantum physics). Therefore, quantum physics exhibits a substantial holism.

Cases such as the singlet state are not at all exceptional. A conceptually similar example can be built up with two systems whose states are entangled with respect to position and momentum (Einstein, Podolsky and [30] Rosen, 1935). Neither system has a definite numerical value of position or momentum. But the two systems taken together have a definite numerical value of the global observables relative distance and total momentum. If position or momentum of both systems are measured, the measurement outcomes are correlated. These correlations are contained solely in the description of the whole.

What is more, whenever we consider a quantum whole which has two or more quantum systems as proper parts, quantum theory tells us that, apart from very exceptional cases, the states of these systems are entangled. This consideration applies also to the physical realm as a whole at the level of quantum systems. We do not need to have recourse to causal relations of interaction in an argument which sets out to establish that entanglement is ubiquitous among quantum systems (compare Scheibe, 1991, p. 228). When we regard quantum theory as telling us something about nature independently of measurements, we are committed to this conclusion.

There are a few elaborate suggestions in the philosophical literature for a characterization of quantum entanglement in terms of holism (Teller, 1986; Howard, 1989; Healey, 1991). I cannot go into these suggestions here. Nonetheless, let us briefly focus on what is known as separability and its failure in quantum theory. Building on Howard, 1989, I propose the following characterization of separability: Physical systems have a state each in the sense that (1) this state completely determines the state-dependent, local properties of the system and (2) the joint state of two or more systems is determined by the state which each of these systems has. This proposal, in turn, suggests the following characterization of non-separability: *The states of two or more physical systems are non-separable if and only if solely the joint state completely determines the state-dependent, local properties of each system and the relations among these systems* (to the extent that these are determined at all). Every case of quantum entanglement thus is a case of non-separability, because solely the joint state of the systems in question taken together completely determines the local observables of each system and their correlations.

Non-separability provides a clue for bringing to the point what is baffling about quantum entanglement: in the mentioned paradigmatic cases we expect properties of the whole such as relative distance, total momentum, or total spin to be determined by properties which the parts have separately. But then it turns out that the parts do not have properties separately which could determine these properties of the whole. The parts do not have a definite numerical value of position, momentum, or spin in a given direction each. But taken together they have a definite numerical value of properties such as relative distance, total momentum, or total [31] spin. The property of relative distance of the whole indicates the way in which the parts are related with respect to position; the property of total momentum of the whole indicates the way in which the parts are related with respect to momentum; and the property of total spin of the whole indicates the way in which the parts are related with respect to spin in any direction. This point can be generalized: In any case of the entanglement of the states of two or more systems, there are properties of the whole which indicate the way in which the parts are related with respect to properties such as position, momentum, or spin in any direction; but the parts do not have these properties separately. (I elaborate on this suggestion for a characterization of quantum holism in Esfeld, forthcoming).

What is the relationship between quantum holism and the holism in Cartesianism? Both are substantial sorts of holism, although not in the same way: the claim that any physical property can only be instantiated if there is the whole of matter is a comprehensive holism. And the thesis that the physical systems at the microphysical level are bound together in the sketched way with respect to basic properties such as position, momentum, or spin in any direction is a substantial holism as well. However, *that sort of holism which Cartesianism includes shows that holism in physics is not tied to non-separability*.

Holism of space concerns all physical systems—because they are identical with points or regions of space—and all physical properties, because they are identical with properties of points or regions of space. Quantum holism, by contrast, concerns only specific physical properties, namely the state-dependent ones (such as position, momentum, and spin in any direction). It is state-dependent whether two quantum systems bear a relation of entanglement to each other. But, as mentioned above, this does not make quantum holism a purely contingent matter. Quantum theory depicts every physically possible world in such a way that entanglement is ubiquitous among quantum systems.

If we lay stress on the fact that Cartesian philosophy of physics admits of a holism and if we take the unification of space and time in relativity physics into account, we arrive at holism of space–time. However, we cannot marry quantum holism to holism of space–time. Holism of space–time is not a viable option as a result of the failure of geometrodynamics. Consequently, quantum holism necessitates a profound revision of the framework of Cartesian philosophy of physics. This revision concerns mainly the following three points:

1) *Localization*: According to holism of space–time, all property instantiations are localized at points or regions of space–time. Apart from [32] spatio–temporal relations, these property instantiations are only connected by interactions which propagate with a finite velocity. By contrast, quantum systems are usually not localized at a point or an arbitrarily small region in space. Quantum holism shows that we cannot conceive all physical systems and their properties as having definite locations in space–time and as being merely connected by causal relations that propagate contiguously with a finite velocity. *We have to acknowledge entanglement as a feature of the physical realm that is at least as basic as the space–time grid and causal relations*.
2) *Separability*: Holism of space–time satisfies separability. We can attribute a state to each point of space or space–time, and this state completely determines the local properties of this point. Furthermore, the joint state of two or more points is determined by the states which are attributed to each of these points. Einstein, 1948, p. 321, claims that classical field theories including general relativity accomplish the principle of separability. Quantum holism, by contrast, implies a reversal of the principle of separability: the joint state of two or more systems is not determined by the states which can be attributed to each of the systems in question. On the contrary, it is only the joint state of two or more systems which completely determines the local properties of each of these systems and their correlations (to the extent that these are determined at all).
3) *Individuality*: Even if we translate the talk of bodies and their motion in space and time in Cartesian physics into the talk of physical properties of regions of space and, ultimately, into the talk of physical properties of space–time points, we still conceive particulars with physical properties that are distinct individuals. Space–time points are the ultimate individuals according to this conception. However, quantum systems are not distinct individuals. If the states of two or more quantum systems of the same kind are entangled, there are no properties which introduce a distinction between these systems (French and Redhead, 1988). Consequent upon quantum holism we therefore have to give up the assumption that the ultimate physical systems are distinct individuals.

My thesis is that since there is a sort of holism within Cartesianism, these three points do not amount to a rejection of Cartesianism, but to its revision. Adopting an attitude of hermeneutic good-will towards Cartesian philosophy of physics, we have to recognize that Descartes—and Spinoza in particular—envisage a substantial holism. Given the conceptual means at their disposal and given the physics of their time, it is reasonable to regard [33] holism of space as the concrete shape which a holism of the physical realm can take within the framework of Cartesian philosophy of physics. Today, the holistic intent which Cartesian philosophy of physics incorporates proves sound—all matter is one holistic system at the microphysical level; but our physics suggests that holism in the physical realm takes another concrete shape. Pursuing Cartesianism in the direction of holism of space or holism of space–time, what is at issue today under this perspective is a change within holism, namely replacing the holism in Cartesianism with another, arguably much more momentous form of holism and spelling out its philosophical consequences.

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