Supplement to Acta Philosophica
FORUM
Volume 3 (2017) 395–404

Hylemorphism in Quantum Physics

Manuel Cruz Ortiz de Landázuri

Universidad de Navarra
mcruz@unav.es

DOI: 10.17421/2498-9746-03-23

Abstract

In this paper I explore Aristotle's notion of matter as a principle of potentiality in order to understand how could be applied to quantum physics. One of the main metaphysical problems concerning the wave function is that it seems to set some sort of indetermination within the physical reality. It is precisely for this reason that I believe that Aristotle's vision of matter as a source of potentiality and indetermination might be a good metaphysical tool that can be applied to quantum mechanics.

CONTENTS

In this paper I would like to analyze in which way Aristotle's notions of matter and form could be valid concepts to help understand, from a philosophical perspective, the structure of reality that appears in quantum mechanics. For this reason I will try to develop these notions in relation with some of Heisenberg's and Popper's statements about the interpretation of the wave function. I believe that Aristotle's hylemorphic theory can help to understand better the wave-particle duality. The new problems that arise from quantum mechanics need to be explained in a new comprehensive framework that cannot ignore the metaphysical questions[1].

1 IS HYLEMORPHISM STILL VALID TODAY?

Aristotle's physics have been seen from the XVII century as a piece of historical science, which is of little interest for the comprehension of nature. The natural world, as described by modern physics, has nothing to do with Aristotle's description of reality: the earth is not in the middle of the universe, the stars don't move around the earth, and things are not made of four elements. Aristotelian physics had nothing to say about how things are. With the replacement of ancient physics by the new mathematical method, modern science reached a great level of improvement. Science rejected the Aristotelian description and also distanced its self from this metaphysical comprehension of reality[2]. The metaphysical notions were of no use in the new science that explained movement and matter with precise mathematical formula.

On the other hand, matter was understood in the new mechanical approach as made of little corpuscles extended in space, homogeneous in quality, differing only in quantity, and being passive objects that receive movement from outside[3]. A new atomistic view of nature was taking place, and the metaphysical notions of matter and form as intrinsic principles of reality was seen as something absurd. Nature was made only of matter as determined and quantified corpuscles with no room for indeterminacy or potentiality. As is well know, this vision of nature and science collapsed with the development of quantum physics in the beginning of 20th century.

2 THE PROBLEM OF MATTER IN QUANTUM PHYSICS

The vision of the microphysical world changed radically with the discovery of quantum mechanics. Max Planck showed how the exchange of energy takes places according to a minimum constant, and came to a conclusion that is quite strange for the classical physicist: there is discontinuity in the energy levels. The problem then was to find a mathematical apparatus that could explain the transitions between energy levels in the atom. Schrödinger's equation was able to explain the energy levels satisfactorily, but now appeared a new philosophical problem for the comprehension of matter.

Essentially Schrödinger's equation describes the electron as a wave function but, as many scientists agreed during the Solvay Conference, it is not a real wave, but rather a wave of probability[4]. This wave describes the probability of finding an electron in a peculiar state[5]. The main question, then, is to know in which sense this wave function can be said to be real.

Schrödinger viewed his ψ wave as a physical wave (a real wave), abandoning completely any idea of localizing the particle in this wave, and forming a picture of the atom which made no place for localized particles: "Something that influences the physical behaviour of something else must not in any respect be called less real than the something it influences –whatever meaning we may give to the dangerous epithet 'real'"[6]. Schrödinger's interpretation seems to be a strong phenomenalistic position according to which what we call reality are just our perceptions. De Broglie, on the other hand, differentiated the ψ (epistemological) wave function from what he called the u-wave, which would be the real wave[7]. However, once admitted that waves and particles are real, the problem would be to know how both of each relate to each other[8].

On the one hand the electrons seem to act as particles when the exchange of energy takes place. On the other hand, they behave like waves in their development along time. Some experiments (specially the double-slit experiment) showed that the electrons cannot be described at all as particles, but rather they behave also as waves. There seems to be a duality between waves and particles that cannot be clarified at all.

Moreover, this duality does not only bring a new vision of space, time and energy, but also of matter. What are the atoms made of? Which is the basic structure of matter? The atomistic and determinist vision had to be abandoned, because the wave-particle duality showed clearly that the main structure of reality is not as determined in space and time as it was thought[9]. Atoms are not corpuscles of static matter, but rather are made of different kinds of particles. These particles, on the other hand, cannot be said strictly to be corpuscles: they behave as waves and as particles. They can be understood as waves in the continuous development along time, they behave like particles in the energetic exchange, introducing a discontinuity in the process. This wave-particle duality seems at first glance to lead to a contradictory vision of reality: how can a wave become a particle?

The problem is even more difficult to solve when regarding the strange character of the wave function as it is described by Schrödinger's equation. This equation describes a wave in a Hilbert space of 3 dimensions for every different particle. For the atom of uranium, with 92 electrons, there would be 276 dimensions, which is obviously a very strange space.

But the main problem of the wave function is that it doesn't describe a real wave, but just a probable wave. If a wave is not real, then it can only describe probability, but this is something absurd: how can probability become a real feature of the natural world? This would be the same as to say that in the natural processes there is an undetermined element (probability) and, even more, that there is some kind of chance in nature. One possible answer would be to say that the probability of the wave function is related only to the limit of our knowledge of the physical world, as when we say that it is probable that it rains today. But the striking point of the wave function is that is not just a matter of knowledge: there are experiments that show that this probability is an intrinsic feature of the quantum particles. It would be like saying that the probability of raining is a real feature of the clouds, rather than a characteristic of our knowledge of the weather conditions. In which sense the waving probability of the elementary particles can be said to be real[10]? Could we say that it is real as a real potentiality or propensity?

3 ACT-POTENTIALITY DISTINCTION AS EXPLANATORY TOOL

The question is: how could we consider the electronic orbits as not real, but just as possible tendencies? From a philosophical point of view this kind of "existence" or "possibility" should be clarified. This is the reason why Heisenberg states:

> "The probability wave of Bohr, Kramers, Slater… was a quantitative version of the old concept of "potentia" in Aristotelian philosophy. It introduced something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality"[11].

The main question is: does the wave function describe something real, or rather should it be understood as a mathematical formalism without reference to any kind of reality? In the first case, if the wave function is something real, it would lead to a very strange comprehension of reality. This is Schrödinger's opinion, who thought that reality consists in waves and the particle aspect of the electron was only its phenomenal manifestation. In other words, according to Schrödinger, there are waves behind our sensible perception[12]. The problem is that we don't know what these waves are (what does it mean to say that the probability-waves exist?), and we can only describe them with mathematical formalism.

In Heisenberg's opinion, the waves should be understood as the mathematical description of a real potentiality. In the same way there is potentiality, there is also probability, and the wave function would describe that probability. This is the reason why he says that the Aristotelian "potentia" has been transformed into a quantitative (or mathematical idea):

> "The most important of these [features of interpretation] was the introduction of the probability as a new kind of 'objective' physical reality. This probability concept is closely related to the concept of possibility, the 'potentia' of the natural philosophy of the ancients such as Aristotle; it is, to a certain extent, a transformation of the old 'potentia' concept from a qualitative to a quantitave idea"[13].

The idea of potentiality seems to explain the wave-function as a middle position between something that is real and something that doesn't exist. But it would be absurd to say that there is a middle term between being and not being without admitting some kind of reality behind it. This is the reason why Aristotle says that reality is made of substances, but there is a principle of potentiality within them: prime matter. It seems necessary, therefore, to say something about Aristotle's notion of prime matter as a principle of potentiality in order to see how it can be compatible with the quantum mechanics interpretation. As D'Espagnat pointed out, the Aristotelian notions of "potentiality" and "materia prima" could have an interpretative role to play in quantum mechanics, but it is necessary to reformulate them in a more precise way[14].

Aristotle tries to explain, against the strong Parmenidian notion of being, that we can talk about being in different ways, that is, that there are different degrees of reality. Aristotle introduces his act and potentiality distinction in order to explain in which way the changes and motions of the world can be said to be real and also explains one of the main characteristics of the physical world: that it is open to new actualizations. He says:

> "That which exists potentially and not in complete reality that is indeterminate (*aoristos*) (*Met.* 1007 b 27)".

Aristotle observes that if there is movement it must be due to some principle of indeterminacy proper to all physical reality. He defines potency as "a source of movement or change, which is in another thing than the thing moved or in the same *thing* qua other (*Met.* 1019 a 15)". The potency is the source of the movement because it brings a real capacity of actualization. It is a real capacity because it implies a range of possibilities that can be actualized. This range of possibilities, nevertheless, won't be actualized at the same time, but rather only one of them will come into actualization. For example, we can take a stone, which is something real, and make different things with it: we can throw it, smash it, or make a statue. The fact of being a material stone is what makes it capable of different actualizations, even though it is only possible to do one of the different possibilities (if I make a statue I cannot throw it). We can say that there is a wave of potentialities in the stone, but none of them will come into the actual unless something in act brings the actualization. This potential aspect of reality is grounded in matter. What is to be material? To have a principle of indeterminacy by which things are not all determined to be what they actually are, and as a consequence they may change to be something different. Aristotle defines matter in the following way: "By matter I mean that which in itself is neither a particular thing nor of a certain quantity nor assigned to any other of the categories by which being is determined (*Met.*1029 a 20).

Aristotle understands matter as the basic substratum of reality, undetermined in itself as a principle of nature, although always determined actually with a specific form. Obviously we cannot find this 'prime matter' in itself, because it is real only as a basic principle of reality. The only things that exist are the substances, and matter is not a substance, but a basic principle present in all substances. Aristotle would say that it is not real in itself, but only real as a basic principle inherent to the physical objects of the world. With other words: Aristotle notices that there is a principle of potentiality and indeterminacy in the physical world that makes possible that something changes and turns to be something different of what actually is.

> "Sensible substance is changeable. Now if change proceeds from opposites of from intermediates [...] there must be something underlying which changes into the contrary state; for the contraries do not change. Further, something persists, but the contrary does not persist; there is, then, some third thing besides the contraries, the matter (*Met.* 1069 b 1-8)".

However, it must be noticed that Aristotle's description of the physical world doesn't finish with this notion of prime matter. On the other hand, his theory of the four elements explains the main structure of reality. It might seem contradictory his philosophy of prime matter with the theory of the four elements, but it must be noticed that he is trying to give an account of two different things.

In some way, prime matter is just a basic principle of reality, and it cannot be found as something in itself. What we may find is matter actualized as water, air, fire and earth. The elements are the first actualization of matter.

As we will see, this is extraordinary significant in order to apply Aristotle's notion of prime matter to quantum physics. The particles are the first actualization of prime matter.

4 POTENTIALITY AND ACTUALITY IN QUANTUM PHYSICS

Turning back to quantum mechanics we might say that the wave function is not the actual, but the potential: a sort of potentiality that tends to a proper actualization (See *Met.* 1021 a 15). But, as Aristotle notices, potentiality only gets into the actual when something in act brings the actualization. It would make sense, then, that we find the electron as particle only in the energetic exchange, because it is when the exchange happens, that something acting from outside brings the potentiality of the wave function into a determined actuality. The transition from the potential to the actual only happens when there is something in act (in this case some energetic stimulation) that makes the transition possible. The wave function, then, is the mathematical description of the wide range of potentialities present in a physical reality, it describes the mathematical configuration of prime matter as an intrinsic principle present in all the physical world.

Could the notions of matter and form be useful to give a realistic interpretation of quantum mechanics? Quantum mechanics shows that matter (whatever it might be) has a potential-probable aspect (described by the wave function) and an actual-corpuscular aspect that is revealed in the exchange of energy. Obviously, the notion of prime matter should be understood in a new way in order to apply it to quantum mechanics.

The wave function describes some kind of formalism that gives structure to the inner potentialities of matter. Matter can be seen as a source of indeterminacy, but this indeterminacy is in some way determined towards certain probabilities, as described by the wave function. On the other hand, if we understand matter as the basic substratum basic to all physical entities, this should be understood as energy that can adopt several forms. This is precisely what Heisenberg states:

> "Actually the experiments have shown the complete mutability of matter. All the elementary particles can, at sufficiently high energies, be transmuted into other particles, or they can simply be created from kinetic energy and can be annihilated into energy, for instance into radiation. Therefore, we have here actually the final proof for the unity of matter. All the elementary particles are made of the same substance, which we may call energy or universal matter; they are just different forms in which matter can appear. If we compare this situation with the Aristotelian concepts of

> matter and form, we can say that the matter of Aristotle, which is mere 'potentia', should be compared to our concept of energy, which gets into actuality by means of the form, when the elementary particle is created"[15].

This prime matter, understood in terms of energy as a source of potentiality, it is always actualized in a determined way (in a concrete energetic manifestation). Here is where the comparison with Aristotle's theory of the elements can be useful to grasp this matter/form distinction. Aristotle thought of the elements as the basic first actualization of prime matter. Matter is the source of potentiality and change, but it is always actualized in some way. The first actualization of matter, according to Aristotle, were the four elements that made up the physical world. Turning back to quantum physics we might say that the first actualization of matter are the particles, which are determined energetic manifestations.

Some similar interpretation of quantum physics can be found in Popper's theory of propensities. Popper thinks that we should admit in the physical world some kind of real possibilities that bring indeterminacy to nature:

> "I believe that the quantum theory is in a very definite sense a particle theory (here I disagree with Schrödinger) and in a sense which excludes a duality, or analogy, or complementarity, between particles and waves. To be more explicit, I believe that the waves (even those of the second quantization) are mathematical representations of *propensities*, or of dispositional properties, of the physical situation (such as the experimental set-up), interpretable as propensities of the *particles* to take up certain states"[16].

Popper explains that propensities are certain capacities of actualization which are present in the physical reality. The waves are, according to Popper, the mathematical representation of propensities. It seems clear that Popper's propensities are close to Arisotle's potentiality. In both cases, it seems necessary to clarify what are these propensities/potentialities based on. There can only be indeterminacy if there is a principle of indeterminacy in all the natural world. That is what Aristotle called prime matter.

5 CONCLUSIONS

I have tried to explore in which way the Aristotelian notion of prime matter as a principle of potentiality in all physical substances could be useful to understand the wave/particle problem in quantum physics. The argumentation has been developed in the following way:

1. There is a potential-probabilistic aspect inherent to the physical reality in his most elementary particles. This potentiality is described by the wave function, which gives a mathematical formalism to predict certain probable states of the electron. These waves of probability are not just an epistemological tool, but rather have some real effectiveness. The problem then is to know if they can be said to be real.

2. Waves could be understood as the potential aspect of the physical world, that is, the mathematical description of potentiality. In this sense, they are not real at all, they are not actual, but they are a real potentiality. They are real as the expression of a real probability. Potentiality is a real aspect of the physical world. To speak about "probability" is to use a mathematical term that can be quite misleading. Perhaps it would be better to say that there is a wave of potentiality (rather than a wave of probability) within the elementary particles.

3. The wave probability is based in a principle of potentiality present in the elementary particles. Here is where the Aristotelian notion of prime matter could be useful to understand the duality wave/particle. In its potential aspect, particles could be understood as waves of probability (they are only as real as the possibilities of actualization). However, in its actual manifestations those particles always appear as defined particles. Prime matter is the source of potentiality: prime energy that can adopt different manifestations.

4. Moreover, it must be noticed that the wave function is a quantitative version of potentiality and prime matter. That is, it reveals the probabilistic aspect of some potentialities. According to Aristotle prime matter was the principle by which something can be transformed into something different. The wave function does not indicate total indeterminacy, but only the probability of finding an electron in some peculiar state. The wave function could be understood as the manifestation of that inner principle present to the physical world which is prime matter.

NOTES

1. See Stöckler, M., *Philosophische Probleme der relativistischen Quantenmechanik*, Dunkler & Humblot, Berlin 1984, pp. 203-210.
2. See Arana, J., *El caos del conocimiento: del árbol de las ciencias a la mañana del saber*, Eunsa, Pamplona 2004.
3. See Capek, M., *The Philosophical Impact of Contemporary Physics*, Van Nostrand, Princeton 1961.

4. See Dirac, P.A.M., *The Principles of Quantum Mechanics*, Clarendon Press, Oxford 1978, p. 7.
5. See Jammer, M., *The Philosophy of Quantum Mechanics*, Wiley-Interscience, New York 1974, p. 33.
6. Schrödinger, E., *Science, Theory and Man*, George Allen and Unwin, London 1957, p. 198.
7. De Broglie, L., *The Current Interpretation of Wave Mechanics*, Elsevier, Amsterdam 1964, pp. 38-39.
8. See D'Espagnat, B., *On Physics and Philosophy*, Princeton University Press, Princeton and Oxford 2006, pp. 201-206.
9. See Dirac, P.A.M., *The Principles of Quantum Mechanics*, Clarendon Press, Oxford 1978, pp. 34-36.
10. "I personally like to regard a probability wave, even in 3N-dimensional space, as a real thing, certainly as more than a tool for mathematical calculations. For it has the character of an invariant of observation; that means it predicts the results of counting experiments, and we expect to find the same average numbers, the same mean diviations, etc., if we actually perform the experiment many times under the same experimental condition. Quite generally, how could we rely on probabilty predictions if by this notion we do not refer to something real and objective?. Born, M., *Natural Philosophy of Cause and Chance*, Clarendon Press, Oxford 1949, pp. 105-106.
11. Heisenberg, W., *Physics and Philosophy*, Harper Perennial, New York 2007, p. 15.
12. See Schrödinger, E., Science and Humanism, Cambridge University Press, Cambridge 1951, p. 131.
13. Heisenberg, W., *The Development of the Interpretation of the Quantum Theory*, in W. Pauli (ed.), *Niels Bohr and the Development of Physics*, Pergamon, Oxford 1962, pp. 12-13.
14. See D'Espagnat, B., *On Physics and Philosophy*, Princeton University Press, Princeton and Oxford 2006, p. 459.
15. Heisenberg, W., *Physics and Philosophy*, Harper Perennial, New York 2007, p. 134.
16. Popper, K., *Quantum Theory and the Schism in Physics*, Rowman and Littlefield, Totowa 1982 (1956), p. 126.
