Fundamental Objects without Fundamental Properties: A Thin-object-orientated Metaphysics Grounded on Structure

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Abstract

The scientific realist wants to read the metaphysical picture of reality through our best fundamental physical theories. The traditional way of doing so is in terms of objects, properties, and laws of nature. For instance, there are families of fundamental particles individuated by their properties of mass and charge, which determine how they move around. One could call this view an object-oriented metaphysics grounded on properties. In this paper, I wish to present an alternative view that one can dub a *thin object-oriented metaphysics grounded on structure:* there are fundamental entities with no fundamental properties other than the one(s) needed to specify their nature. I argue that my view has several advantages over the received one. In particular, I compare my proposal to the traditional view in the quantum domain and I argue that my view provides a better fit for both approaches to quantum metaphysics, namely the primitive ontology programme and wave-function realism.

1. Introduction

Metaphysicians in the naturalized tradition as well as scientific realists have developed many views about the nature of reality. These views have in common a 'traditional core' according to which fundamental entities inhabit space and evolve in time according to the laws of nature. The fundamental entities could be for instance particles, as in the classical world, or particles and fields, as in classical electrodynamics. Their difference in nature is captured by their mathematical description: while particles are (exhaustively) mathematically described by points in three-dimensional space, fields are functions that assign to each point in space a field value. Laws of nature govern the behavior of such things: in a classical world for instance Newton's law determines where the particle are at other times, given the description of the system at one time. To close the circle, one further assumes that the fundamental entities can be though as composed of different families. For instance, in case of classical electrodynamics, particles divide into protons, electron and neutrons, and each family is identified by having specific masses and charges. That is, particles in different families move

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differently under the same circumstances because their fundamental properties are different. If one like labels, one can call this view an *object-oriented metaphysics grounded on properties.* In this paper I wish to explore an alternative approach that one can label a *thin object-oriented metaphysics grounded on structure*: there are no intrinsic properties *other than* the one(s) necessary to identify the nature of the fundamental objects. That is, assuming the world is made of particles, they merely have the property of being located in space, which is the only property necessary to characterize them as particles (as opposed to, say, fields). Particles have no further properties: no mass and no charge. Their behavior is accounted for in terms of structural relations encoded in the laws of nature. In this paper I am going to argue that this view is better than the traditional view, especially when looking at the quantum domain, where it provides a nice fit for both of the main proposal for quantum metaphysics, namely the primitive ontology approach and wave-function realism. After discussing the traditional view in section 2, I present my view in section 3, where I also show its extension to the quantum domain. Before concluding in section 5, I present in section 4 the advantages of this view over the traditional view, and respond to possible objections.

2. The Traditional Core

Restricting ourselves to the entities of the natural world, metaphysics aims at explaining physical phenomena. Setting aside the so-called 'a priori' metaphysics, which is independent from empirical sciences, 'naturalized' metaphysics is informed by science. The debate between a priori and naturalized metaphysics is connected with the issues surrounding realism and anti-realism in the philosophy of science. Scientific realism fits well with naturalized metaphysics, for it maintains that we are justified in considering our best scientific theories as (approximately) true. Therefore, in this tradition one looks at natural sciences in order to individuate the nature of fundamental entities, their properties, and the laws that govern their motion. While there are several objections to scientific realism in this paper I assume it to be tenable both in the classical and the quantum domain.

2.1 Objects, Laws and Properties

The various traditional object-oriented views in metaphysics have a common core. I call this core the *traditional view*. It comes down to four elements: space-time, fundamental things, their intrinsic properties, and laws of nature. First, there is space and time, or space-time: the arena in which the fundamental objects live. For instance, in a classical world the fundamental objects are point-particles. Mathematically, their nature as particles results in the fact that they are completely specified by their location in space. Newton's second law (i.e. the force F acting on an object generates an acceleration a proportional to its mass m, or $F = ma$) and Newton's law of gravitation (i.e., two objects attract each other in a way that depends directly on their masses m_1 and m_2, and inversely to their relative distance r_{12} squared: $F_{grav} = G\frac{m_1 m_2}{r^2{}_{12}}$, where $G = 6.67408 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\text{s}^{-2}$ is the gravitational constant) determine how the particles evolve in space through time. Other possible ontologies are material fields. In contrast to particles, they are extended objects that occupy the whole space, and whose intensity changes from point to point. Arguably (more on that in section 4.1) in classical electrodynamics one introduces the electromagnetic fields E and B as fundamental entities together with the particles. Both of these entities evolve in time in a way described by the fundamental laws of nature: Maxwell's equations determine the evolutions of the fields,[2] and the electromagnetic force ($F_{EM} = qE + qv \times B$, where q is the signed charges of the body, and v is its velocity) together with Newton's second law ($F_{EM} = ma$) account for the action of the fields on the particles. The temporal evolution of the particles can be described as a trajectory in space-time, and the evolution of the fields as a propagation of a wave in three-dimensional space. However, the traditional account needs more in order to successfully recover the empirical data: particles need to have *mass* to explain why a massive body behaves differently from another massive body under the same circumstances. If body 1 and body 2 have respectively masses m_1 and m_2, given the law of gravitation F_{grav}, body 1 is accelerated toward body 2 with acceleration $a_{12} = \frac{F_{grav}}{m_1}$ and body 2 is accelerated toward body 1 with a different acceleration, namely $a_{21} = \frac{F_{grav}}{m_2}$. [3] In classical electrodynamics one needs also *charge* in order to account for the actual experiment outcomes. If particle 1 and particle 2 have the same mass but 1 turns left in a given magnetic field while 2 turns right, then this is explained by them having different charges. In the traditional account, therefore, one can divide particles as belonging to distinct families, for instance one is an electron and another is a proton, in virtue of their different masses and charges.[4] An electron, say, is defined in virtue of its properties, which therefore are *intrinsic* to it: its mass, $m_e = 9.11 \times 10^{-31}\ kg$, and its charge $q_e = -1.60 \times 10^{-19}\ C$ determine its nature. In this

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[2] For completeness, Maxwell's equations are as follows: $\nabla \cdot E = \frac{\rho}{\varepsilon_0}, \nabla \cdot B = 0, \nabla \times E = -\frac{\partial B}{\partial t}, \nabla \times B = \mu_0 \left(J + \varepsilon_0 \frac{\partial B}{\partial t}\right)$, where ρ is the chare density and J the current density (the rate of change of charge per unit area). They can be rewritten as $\frac{\partial^2}{\partial t^2}E - \frac{1}{\mu_0 \varepsilon_0}\nabla^2 E = 0$, $\frac{\partial^2}{\partial t^2}B - \frac{1}{\mu_0 \varepsilon_0}\nabla^2 B = 0$, where $\varepsilon_0 = 8.85 \times 10^{-12}\ F \cdot m^{-1}$ (the vacuum permittivity) and $\mu_0 = 12.57 \times 10^{-7}\ N \cdot A^{-2}$ (vacuum permeability), which is an equation for a wave propagating with velocity $v = 1/\sqrt{\varepsilon_0 \mu_0}$, which is the velocity of light c.

[3] I assume reductionism, so the mass of macroscopic objects is (suitably) the sum of the masses of their fundamental constituents. Notice that in classical mechanics as developed originally by Newton, who knew nothing of protons and electrons, all fundamental particles have the same mass and therefore macroscopic bodies behave differently only if they contain a different number of particles.

[4] The fact that protons are actually not fundamental particles is not relevant here. The example is just supposed to simplify the situation.

sense, fundamental objects are *thick*: they are 'dressed up' with properties. Nonetheless, all fundamental entities follow the same laws of motion: the fields obey Maxwell's equations, the particles follow Newton's second law $F = ma$, supplemented by the laws of the forces given by F_{grav} and F_{EM} above, so that $F = F_{grav} + F_{EM}$.

So, given the ontology, there is *one fundamental law, and many fundamental properties,* and thus families of the same kind of fundamental entities. That is, let us minimize the number of fundamental laws (e.g. Newton's second law, the law of gravitation, Maxwell's laws of electrodynamics), and add fundamental properties as needed to allow the empirical adequacy of the theory. This would in turn multiply the number of fundamental kinds of entities.

Many debates are connected to the traditional core, each connected with its fundamental element.[5] In particular, because in the traditional account properties play a mayor explanatory role, the debate about the nature of intrinsic properties has gained a lot of attention. The divide is between categorical properties and dispositional properties. However, even the definition of what counts as one or the other is controversial.[6] For instance, one can say that a property is dispositional when its essence depends on what it prescribes its bearer to do. In contrast, a categorical property is defined as not connected to this. This could mean that a property is categorical when its essence does not depend on what its bearer is, or that they are the properties which remain the same in all possible worlds. Still, it is not clear whether the two definitions are compatible. An example of dispositional property is solubility: a substance has such a property if, when placed in water, will dissolve. On a more fundamental level mass and charge may be dispositional properties since they determine what the particle bearing a given mass, say, is disposed to do when subject to a force. However, mass and charge can also be seen as categorical properties: they identify what an electron, say, is in all possible worlds. Other examples of categorical properties are location and spatial relations (Ellis 2010). Moreover, among dispositional properties one finds causal powers (such as mass), which allegedly intervene in causal processes, and propensities (such as half-lives of radioactive elements) which are such that the activities of their bearers do not depend on the circumstances (they are 'absolute' dispositions).[7]

[5] First, we have the problem of the nature of space and time: is space a substance or it merely consists on relations between objects? Then, we have the discussion over the nature of laws: one finds Humeans, who believe that laws are the axioms and postulates of the best theory of the world, (broadly understood) necessitarians, who argue that laws are over and above physical events, and primitivists or anti-reductionists, who maintain that laws are their own metaphysical category.

[6] See Mumford (1998), Bird (2007), Ellis 2010 for some attempts to characterize categorical properties, versions of sophisticated analyses of dispositions have been offered by Prior (1985), Lewis (1997), Malzkorn (2000), Mellor (2000), Fara (2005), and Manley and Wasserman (2008).

[7] The debate over the nature of properties is connected with the debate over laws of nature since Humeanism requires a strong differentiation between dispositional and categorical properties, since

2.2 The Traditional View in the Quantum Domain

Aside from the problem of suitably defining properties, the most sever challenge to the traditional approach is its extension to the quantum domain. First, it is not obvious that quantum theory is compatible with scientific realism, and even so it is not obvious what its ontology is. In contrast with classical theories, it is not clear what the underlying metaphysical assumption is: what is matter made of, in this theory? Upon opening physics books one finds a mathematical entity and an equation standing out: the wave-function and its temporal evolution equation, called the Schrödinger equation. So, one natural thought is to take this entity as describing the fundamental ontology. However, as emphasized by Schrödinger himself (1935), this is problematical because of the so called *measurement problem* or the problem of the Schrödinger cat: given that the wave-function is supposed to represent every physical object, and given that it is a wave, it can superimpose also at the macroscopic level, which is something that we never observe. For instance, we have never seen a superposition of a dead-and-living cat.[8] Many physicists react to the cat problem conceding that quantum mechanics is contradiction-ridden, and thus it is unsuitable to describe reality. They therefore conclude that we have no choice but to become anti-realist: at best, quantum theory can describe measurement results. However, in the last 60 years many quantum theories compatible with a realist interpretation have been proposed, such as the pilot-wave theory,[9] the spontaneous localization theory,[10] and the many-worlds theory.[11] Mathematically speaking, the pilot-wave theory is one in which, in contrast with the common understanding, the complete description of a physical system is given by the wave-function and by the particles' location. Accordingly, two equations define this theory: the Schrödinger equation for the wave-function, and the guidance equation for the particles, which describes how their velocity is governed by the wave-function. In

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Humean supervenience is expressed in terms of categorical properties ('perfectly natural properties') which fully determine dispositional properties.

[8] The reason this is often called the measurement problem is has to do with the positivistic influences of some of the founding fathers of quantum mechanics were under. The only moment they saw these unobserved macroscopic superpositions to be problematic was in a measurement situation: we want to measure the position of this particle; the result is that it is the superposition of the-detector-on-the-right-having-clicked and the-detector-on-the-left-having-clicked; this is not what we observe because only one detector will click; so something has to happen that changes the evolution of the wave-function during the measurement process. However, a measurement process is like any other physical process, and therefore, the theory is not able to describe reality.

[9] The theory was originally proposed by de Broglie (1928), and developed later by Bohm (1952). This is why in recent years it has been commonly dubbed Bohmian mechanics.

[10] This theory is also often called GRW theory from the names of its proponenst Girardi, Rimini and Weber (1986).

[11] The theory originally comes from Everett (1957), sometimes therefore it is called Everettian mechanics.

this theory, only the part of the wave-function 'under which' the particle is matters for its future behavior, and thus getting rid of the superpositions for all practical purposes. In the spontaneous localization theory, the wave-function is usually thought as providing the complete description of any physical system, but it evolves according to the Schrödinger equation only until a random time, and then it instantaneously localizes around a random point, effectively eliminating the (macroscopic) superpositions. This so-called GRW-evolution involves two new constants: the rate of collapse (per 'particle') $\lambda = 10^{-15}\mathrm{s}^{-1}$ and the width of the collapsed wave-function $\sigma = 10^{-1}$ m. Finally, in the many-worlds theory the complete description of the system is given by the wave-function which evolves according to Schrödinger's equation. The basic idea is that the two terms of the superposition that describe a living and a dead cat both exists even if they are never observed: the terms of the superpositions interact so little that they can be interpreted as living distinct 'worlds' occupying the same region of space-time.

There is a sense in which the ontology of this theory is naturally given (at least partially) by the wave-function. That is, the most straightforward way of understanding the mathematics of these theories is to assume that the wave-function represents matter: in the pilot-wave theory, there are both particles and weaves, while in the spontaneous localization theory and in the many-worlds theory the wave-function evolves differently but equally describes physical objects. This view, dubbed *wave-function realism,* is (partly[12]) motivated by considerations arising from the comparison with what we did in the case of the classical theory. In classical mechanics, the fundamental equation is an equation for points in three-dimensional space. From this, we inferred that matter was made of point-like particles in three-dimensional space (or point-like particles in spatio-temporal relations between one another). Since in quantum mechanics (what is regarded as) the most fundamental equation, Schrödinger's equation or the GRW evolution, is an equation about the wave-function, similarly we should conclude that matter is represented by the wave-function.[13] Notice however that the wave-function by construction is an object that lives on configuration space, which classically is defined as the space of the configurations of all particles. As such, it is a space with a very large number of dimensions, while one would expect a physical object to live in three-dimensional space: call this the *configuration space problem (*or the macro-object problem). Wave-function realists therefore argue that what we take to be three-dimensional particles are instead emergent or derivative, and that configuration space is best seen as the space of the 'degrees of freedom' of the system. In this

[12] Ney (forthcoming) makes the case that another main motivation for this view is to have a separable and local metaphysics. See section 4.1 for a little more on this.

[13] See Albert and Ney (2013), and then most notably Albert (1996, 2103, 2015), Lewis (2004, 2005, 2006, 2013), Ney (2012, 2013, 2015, 2017, forthcoming), North (2013).

framework there are two main attempts to recover the macroscopic objects from the wave-function. The first is due to Albert (2015) and based on a functionalist reduction of three-dimensional microscopic objects from the wave-function. The idea is that it is possible first to define functionally what it means to be a three-dimensional object, and then it is possible to show that the wave-function can play that role. This functional reduction can give rise to microscopic three-dimensional objects, which then can be understood as usual, in particular as composing macroscopic objects. Ney (forthcoming) is critical of this approach, as she points out that in this reading there is no common three-dimensional space for inter-particle interactions. She therefore proposes her approach, in which she gives a privileged role to symmetries: she observes that only a three-dimensional 'decomposition' of the wave-function (as opposed to any other kind of decomposition) can explain symmetry properties, and because of this reason it makes sense that we represent our world three-dimensionally rather than (say) two-dimensionally. Thus in her view three-dimensional objects exists, not as an additional postulate of the theory but as derivative from the wave-function when considering symmetry properties as fundamental facts about the world.

Another approach to quantum metaphysics is the so-called *primitive ontology* approach,[14] which follows the lead of scientists such as de Broglie, Lorentz, Einstein[15] and (interestingly enough) Heisenberg[16] in the 1920s, who, did not think that the wave-function should be thought of as material. The problem they think is going to be harder to solve is the configuration space problem: the wave-function does not live in three-dimensional space, and as such it is not suitable to represent physical entities. The idea instead is that the most straightforward and direct way of making a connection between our observations and what is postulated by the theory is to assume that matter is made of three-dimensional stuff. For instance, it could be particles, (three-dimensional) fields, spatio-temporal events (sometimes called 'flashes'). Classically, as we have seen in the traditional core, we explain the behavior of macroscopic things by assuming that they are composed of microscopic things, and in the primitive ontology approach this straightforwardly follows also in the quantum domain. Note that in this approach the wave-function does not represent matter but it is controversial what it actually is. Some have argued it is a property of matter.[17] However, its role in the theory does not seem to be straightforwardly the same as the one of properties: the role of properties in fact is to distinguish different kinds of fundamental entities, and this is not what the wave-

[14] Dürr, Goldstein, Zanghì (1992), Allori (2103a,b), Allori (2015) and references therein.
[15] See Bacciagaluppi and Valentini (2009) for an interesting discussion of the various positions about this issue and others at the 1927 Solvay Congress.
[16] Heisenberg very vividly said to Bloch (1967), referring to configuration space realism: "Nonsense, […] space is blue and birds fly through it".
[17] Monton (2013), Lewis (2013) Esfeld et al. (2014) Suàrez (2015) Solé (2015) and references therein.

function does; rather it helps generate the law of evolution of physical objects. Therefore, more fitting seems to be the view that the wave-function is nomological, or quasi-nomological: the wave-function is better understood as part of the law of nature.[18] In fact the wave-function behaves similarly to other entities we label as 'law-like' in classical mechanics, like for example potentials: matter is not 'made of' them; rather, they help defining the law for matter, just like the wave-function in the quantum domain. If so, we are not really adding anything mysterious to the picture. The complicating feature is that the wave-function evolves in time, which however is not too concerning in a Humean account of laws.[19] However, perhaps better is the idea that the wave-function should be understood structurally, which is what I am defending in this paper.

So, to summarize, under the assumption that quantum theory can be interpreted from a realist perspective, the situation seems to be as follows. On the one hand it seems that also in the quantum domain we need properties to explain why things behave differently in the same circumstances. Indeed, we add more properties, such as spin, to explain the behavior of more particle types: for instance, we talk about bosons (which share the properties of having integer spin) and fermions (which instead have half-integer spin). On the other hand there are two approaches to quantum metaphysics, wave-function realism and the primitive ontology approach. In the case of the former, because of the ontological and explanatory continuity between the classical and the quantum domain, it seems that the traditional view may hold just as well, we just need to add more properties to the mix. However, the situation is more troublesome in the case of wave-function realism. In fact while in the traditional view properties did the majority of the work in explaining the behavior of things, nothing like that happens here. While in the traditional view one explains why electrons go up in a magnetic fields and protons go down by invoking the fact that they have opposite charge, in this context matter is described by the wave-function and its fundamental property is (presumably) its field value. In Albert's approach three-dimensional objects are 'functional shadows' of the high dimensional wave-function, which does not naturally or obviously 'carve up' into different properties to assign to the different shadows. All matter is the described by the same wave-function, with the same field value. So, Albert's theory explains the electrons going up in a magnetic field not by invoking the property of the wave-function, but rather by saying that there is something in the wave-function that plays the functional role of the electron, namely to go up in a magnetic field. In Ney's account something similar happens: electrons exists because, among all the decompositions of the wave-function, the one privileged by symmetries is the three-dimensional decomposition. This decomposition shows 'particle-like' entities which

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[18] Goldstein and Zanghì (2013), Allori (2018) and references therein for criticisms and replies.

[19] See. e.g. Callender (2015), Miller (2014), Bhogal and Perry (2017), Esfeld (2014).

appear to have charges in the sense that they go up in a magnetic field: they go up because that is what that decomposition of the wave-function ends up doing. So, in both cases 'electrons' exist derivationally from the wave-function, and appear to have properties insofar as their behavior allows us to use that kind of talk. That is, what emerges derivationally from the wave-function (either structurally or using symmetries) is the object, not its properties. In other words, in this approach, property talk is *purely fictional:* we can use it, but it is not fundamental. The most fundamental explanation of the behavior of macroscopic objects is instead the one given by the wave-function and its temporal evolution.

So it seems to me that, while in the case of the primitive ontology approach the traditional view *may* still be viable, within wave-function realism it would be a stretch to think of explanation in terms of properties of fundamental objects as the traditional approach suggests. Instead, in the next section I propose a view which I argue should be preferred to the traditional view for general reasons, but it also provides a good fit for both the primitive ontology approach and wave-function realism.

3. Fundamental Entities without Fundamental Properties

My approach is an alternative to the traditional account. I argue in this section that my approach has several advantages over the traditional approach, over the approaches proposed by the wave-function realists. My view requires a fundamental re-interpretation of the role of laws of nature, which I think is best understood in structural terms. The basic idea is that, as in the traditional account, there is space-time and there are fundamental entities. Yet, these entities have *only one fundamental property*, namely the one that *uniquely characterizes its nature*. For instance, if the fundamental ontology is particles, their only property is their spatial location. If the world is instead made of fields, their only property is having a set of intensity values for every point in space. In contrast with the traditional account therefore there are no different families of the fundamental entity that constitute matter. That is, *all fundamental entities are identical:* there is just one kind. That is, if the fundamental ontology is particles, all particles are identical: there are no different families of electrons, protons and neutrons.

A first reaction to this would be an immediate dismissal: we already tried, and failed. One *has* to add properties to account for the different behavior under the same circumstances. However, I think this rejection is too hasty: one could suitably account the observed different behavior of particles *appearing* to belong to different families in terms of laws of nature. This can be done by introducing the notion of 'effective law:' fundamental entities behave differently in the same situation because they are *governed by different effective laws*. Effective laws are different ways in which the same (kind of) law can be implemented, and there is one effective law for what appears to be a different family of ontology in the traditional approach. For instance, in a particle theory, there are as many effective laws as there seem to be families of particles. Thus, the main idea is the opposite of the traditional view: let us *minimize the fundamental properties, allowing for as many effective laws of nature as needed to make the theory empirically adequate.* In other words, there is a network of structures between the fundamental entities that can be captured in terms of general laws which are implemented differently through effective laws. Let me elaborate on this in the next section.

3.1 Thin Objects, Effective Laws, and Symmetries

Consider Newton's law of gravitation $F_{grav} = G\frac{m_1 m_2}{r_{1,2}^2}$. It contains the gravitational constant G, which is fixed and immutable. This is the case also for the other forces, including the electromagnetic force, where two constants ε_0 and μ_0 are 'hidden' in the equations of the evolutions of the fields. These constants are part of the definition of the *law*. In addition, there are other parameters, like masses and charges. They are different from constants: they appear in laws but *they are part of what defines matter*. In fact, constants remain identical independently of the objects the law applies to, while masses do not. As we saw, in the traditional account one recovers the empirical data by postulating that particles have certain properties, over and above their spatial location, and accordingly there are different fundamental families. In contrast, in my view there is no such distinction, and empirical adequacy is obtained by introducing effective laws. That means that the parameters in the law, namely the values of the fundamental masses and charges, are seen as *part of the definition of the law* too, together with the constants. For example, assume that in the traditional view there are three families of particles: electrons, protons and neutrons. Thus, we have six parameters: the three masses m_e, m_p, m_n, and the three charges q_e, q_p, q_n,. Now, forget the charges for the moment and focus on Newton's gravitational law. One can rewrite it for an 'electron' as follows: $F_{'electron'} = \frac{H_1}{r^2}$, where $H_1 \coloneqq G m_e M$, where and M is the mass of a reference body that generates the force. For all families, the form of the law (its kind, if you prefer) is the same: its intensity is proportional to $\frac{1}{r^2}$. However, there is a different constant H_i for each kind of 'fundamental particle' so that to each is associated an effective law $Eff\ law_i = \frac{H_i}{r^2}$, where $i = 1,2,3$ is associated to one of the three 'families.' There is one effective law for the 'electron' $Eff\ law_1 = \frac{H_1}{r^2}$, where $H_1 = G m_e M$, one for the 'proton', $Eff\ law_2 = \frac{H_2}{r^2}$, where $H_2 = G m_p M$, and one for the 'neutron', $Eff\ law_3 = \frac{H_3}{r^2}$, where $H_3 = G m_n M$.

In other words and to sum up, in my view matter is represented by *stuff* in three-dimensional space whose nature is specified by our best theory as the simplest and most explanatory. In classical mechanics, this stuff is particles. As already said, in my approach there is just one kind of fundamental entity whose only property is the one that defines their nature. Classical particles have only one property, namely their position in three-dimensional space, since it determines their nature of particles (as opposed to fields, say). Moreover two fundamental entities differ only because they differ in behavior under the same circumstances, and this is accounted by assuming that they are governed by different effective laws $Eff\ law_1$ and $Eff\ law_2$. This is easy to see in classical electrodynamics. Pictorially, in the traditional view electrons, say, are red dots in space-time, protons are yellow ones, and neutrons are green ones. Since their temporal evolution is described by the same law, they follow respectively the red, the yellow and the green trajectories. Instead in my approach an electron is a point which has no color which follows the red trajectories generated by $Eff\ law_1$, a proton is a point which has no color which follows the red trajectories generated by $Eff\ law_2$ and a neutron is a point which has no color which follows the red trajectories generated by $Eff\ law_3$.

Moreover, as we saw in section 2.1 in classical electrodynamics one introduces the fields as part of the fundamental ontology to make the theory empirically adequate: the fields appear in the force $F_{EM} = qE + qv \times B$ and affect the particle trajectory in virtue of its charge. However, in the spirit of this approach it seems more natural to think of the *fields as part of the law*, just like the particle properties. Consider the example above, this time focusing on the electromagnetic force. For simplicity, consider only the Coulomb force: $F_{Coulomb} = k\frac{q_1 Q}{r^2}$ (where $k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9\ N\ m^2\ C^{-2}$ is Coulomb's constant, generated by particle with charge Q and acting on the particle with charge q_1). One can define the electric field as $E = k\frac{Q}{r^2}$. Thus, $F_{Coulomb} = q_1 E$. If particle 1 is an 'electron', one can rewire this as follows: $F_{electron} = q_e E = \frac{K_1}{r^2}$, where $K_1 \coloneqq kq_e Q$. As in the gravitational case, for all particles the form of the law is the same: it is an inverse square law. However, there is a different proportionality constant K_i for each kind of 'fundamental particle' so that to each is associated an effective law $Eff\ law_i = \frac{K_i}{r^2}$, where $i = 1,2,3$. In this way, not only there are no particle families, there are *no electromagnetic fields either*! They are 'absorbed' into the definition of the law as well: one law for the 'electron' $Eff\ law_1 = \frac{K_1}{r^2}$, where $K_1 = kq_e Q$; one for the 'proton' $Eff\ law_2 = \frac{K_2}{r^2}$, where $K_2 = kq_p Q$, and one for the 'neutron' $Eff\ law_3 = \frac{K_3}{r^2} = 0$, because the neutron has no charge and thus$K_3 = kq_n Q = 0$.

One important reason, perhaps the most important one, to question that electromagnetic fields are part of the material constitution of the world has to do with symmetry properties.[20] In fact, as explained below, it turns out that they transform in a way that is *dissonant* with their apparent nature. Roughly put, symmetries are transformation that do not affect the applicability of the theory. For instance, Newtonian mechanics being translation invariant implies that it equally describes the

[20] However, for other arguments against a field ontology, see Mundy (1989) and Lazarovici (2017).

actual world and a world exactly like it but translated one meter to the left, say. Among others symmetries, classical electrodynamics is taken to possess also time-reversal symmetry.[21] A time-reversal transformation reverses time, and roughly a theory is said to be time-reversal invariant when the world 'running forward' and the world 'running backwards' are both described by the theory. Assume that in classical electrodynamics there are both particles and fields. Particles are defined as points in three-dimensional space, but what about the fields? One natural way to think about them is as vector functions: they associate to each point in three-dimensional space their field values in forms of vectors. As such, they would not change under a time-reversal transformation: why would a field value change if part of the forward-running world or the backward-running world? However, since for classical electrodynamics to be time-reversal invariant the magnetic field in the backward-running world would have to change sign, the theory loses a symmetry, and this does not seem desirable. Another way of think about electric and magnetic fields is as respectively a polar vector (or merely a vector) and an axial vector (or pseudo-vector) which transform as needed to preserve invariance. A pseudo-vector transforms like a vector under rotation, but it changes sign under reflection, accounting for the behavior of the magnetic field changing under a time-reversal transformation needed to preserve invariance. Yet, one needs to provide additional independent reasons to believe that the true nature of the fields is the one proposed: why would the magnetic field be a pseudo-vector if it looks like a vector? An explanation is given by my approach: if one wants to keep the symmetry, one should not allow the fields to represent physical objects. And assuming that they do not, then we can allow the fields to transform as needed to allow the symmetry is preserved. This amounts to define the electric and the magnetic fields respectively as a true vectors and a pseudo vector. Similar consideration will also be true in the case of the wave-function, as we will see below: only if one think of it as non-material, we can account for certain symmetries of the theory.

To summarize, in my view we have *thin objects*, individuated by their only natural property, namely by the property that uniquely characterizes their nature. In this sense therefore the objects in this approach are 'thin.' Then the law of nature determines how they evolve in time. For the theory to be empirically adequate, the law has to break down into a set of effective laws, each of which applies to a subset of the set of fundamental objects. The laws and the effective laws are naturally seen as a *structure*, a network of relations, between the thin objects.

Before we proceed, I wish to make a couple of remarks. The first is on the use of the term 'structure.' In my view one has identical thin objects, each governed by an effective law, which is a specific instantiation of the fundamental law of nature, which

[21] For a discussion on the meaning of time reversal symmetry and its implication for classical electrodynamics see Allori (2015) and references therein.

includes parameters that capture what we call in the traditional view 'properties' of the fundamental objects. There are many question that immediately come to mind, some of which have to do with ontological priority: does the fundamental law exist over and above the thin objects? Do the effective laws exist over and above the fundamental law? These questions are the typical questions one asks when investigating the metaphysics of laws, and have Humean and non-Humean perspectives: while the Humean maintains that laws supervene on the arrangements of matter, the non-Humean disagrees. I will bypass the whole debate by simply assuming that one can be neutral about the metaphysical status of laws and endorse a structural approach: regardless of whether one is Humean or not with respect to laws, the set compose of the fundamental law and the effective laws can be seen as a set of relations between the thin objects. They are a structure which, regardless of whether it supervenes of not on matter, describes how matter behaves. And this is sufficient for the purpose of this paper.

The second remark instead has to do with symmetries. In this approach *symmetries help identifying the true nature of objects*: if we allow electromagnetic fields to be objects then the theory loses an important symmetry, so they should be regarded as part of the law. To put it differently, there is a sense in which *symmetries give indications on what the law is*. If one also adds simplicity considerations, one may argue that symmetries allow to generate the law for the thin objects. While undoubtedly there is no logic of theory construction, one could notice that historically laws of nature were proposed in the context of a given theory using symmetry considerations. Take the case of classical electrodynamics. As we have seen, one needs fields in order for the theory to be empirically adequate. However, how should they transform? As we have seen, they would transform as to preserve certain symmetries of the motion of the particles. Similar considerations have been used also in the quantum domain: in the pilot-wave theory discussed in the next section the law of evolution of the particles is obtained entirely using symmetry (and simplicity) considerations.[22] Moreover, relativity theory was developed, together with the light postulate, using a symmetry principle, namely the principle of relativity, which was adopted by Einstein solely with the purpose of

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[22] This is how Dürr Goldstein and Zanghí (1992) infer the laws for the trajectories of particles in the pilot-wave theory. The consideration that a first order derivative of position is simpler than a second order one, leads to an equation for the velocities so that the k −th particle will move according to $\frac{dq_k}{dx} = v_k^{\psi}(q_1, \ldots, q_N)$, where is a Schrödinger evolving wave-function. Moreover, the fact that two wave-functions that differ by a constant are physically equivalent leads to the fact that the velocity needs to be a homogeneous of degree 0 as a function of the wave-function, that is $v_k^{c\psi} = v_k^{\psi}$, where $c \neq 0$ is a constant. Asking for rotational invariance one gets $v_k^{\psi} = \alpha \frac{\nabla\psi}{\psi}$, where α is a scalar constant. In addition, time-reversal invariance is implemented for the wave-function as a transformation into its complex conjugate $\psi \longrightarrow \psi^*$, which leads to $v_k^{\psi^*} = -v_k^{\psi}$, and thus $v_k^{\psi} = \alpha \Im \frac{\nabla\psi}{\psi}$. Finally, Galilean invariance requires $\alpha = \frac{\hbar}{m}$, given that the wave function transforms as $\psi \longrightarrow e^{i\frac{m}{\hbar}v_0 q}\psi$.

restricting the form of the law. In addition, Wigner and Weyl were among the first to recognize the great relevance of symmetry groups to quantum physics, which were (and still are) systematically used to construct new models and theories, similarly as how now in string theory we have dualities. This kind of considerations should be taken with a grain of salt, as epistemological considerations about how a theory has been proposed not necessarily track ontology. However, it seems to me that if one could show that symmetry considerations are enough to select *one* particular law of nature among the infinite possibilities as well as a type of ontology, then one would have further simplification of the explanatory structure: from symmetries one would get the type of law and the type of objects, and from further considerations about empirical adequacy one would get the effective laws. In turn, from this one would then explain the 'apparent' properties of matter. For instance, in classical electrodynamics one would have a particle ontology, from simplicity and symmetry considerations: particles are simpler than fields, mathematically, and if we allow fields then we lose symmetries. Then we have a type of law for the particles, the inverse square law, based on considerations of empirical adequacy and simplicity. Effective laws, however, need to be postulated in addition to the law: there is noting that tells us, merely from using symmetries, how many particle types there are, in the traditional language, which means that there is nothing in the symmetries that tells us how many effective laws one needs in order for the theory to be empirically adequate.

3.2 Extension to the Quantum Domain

In this section I show how this view extends nicely in the quantum domain, regardless of whether one endorses the primitive ontology approach or wave-function realism. Let us see how that is first in the case of the primitive ontology approach. As we have already discussed, within this framework, matter is represented by (microscopic) variables in three-dimensional space (or four-dimensional space-time). Because of the more or less straightforward classical-to-quantum continuity, this view can naturally be read as saying that matter has no property other than the one that determines its nature. To close the circle, within quantum mechanics matter evolves in time according to a law that involves the wave-function, which is taken to be part of the definition of the laws. Every quantum theory can be analyzed in these terms, and each of them provides a picture of the world in terms of its (more or less natural) fundamental entities. For instance, consider the pilot-wave theory. Matter is constituted by particles, whose law of evolution involves constants, such as $\hbar = 1.05 \times 10^{-34} m^2 kg/s$ which is the reduced

Planck's constant, and parameters such as masses.[23] Following the approach developed in this paper, this laws breaks down into a series of effective laws by considering the parameters as part of the law too.[24] In the spontaneous localization theory one may have a particle primitive ontology whose evolution is implemented by a GRW-evolving wave-function.[25] In this theory the law of nature is the law of the particles' motion, which is the same as the one of the pilot-wave theory (with qualification[26]). Thus, one can similarly define the effective laws using the particles masses as new constant in addition to the GRW constants λ and σ.[27] Alternatively, one could assume that the fundamental entity is a scalar field in three-dimensional space representing the matter density of things, defined in terms of the wave-function.[28] In the reading I am proposing, assuming that there are, say three 'particle' kinds (electrons, protons and neutrons), each associated traditionally with mass m_i, $i = 1,2,3$ then the total matter density field M^ψ such that $M^\psi(x,t) = M_1^\psi(x,t) + M_2^\psi(x,t) + M_3^\psi(x,t)$, located in three-dimensional space.[29] The matter density $M^\psi(x,t)$ has no property other than the field values assigned by the formula above. Also, the expression for this field defines the law of nature of the theory, namely the law of evolution of the matter density in terms of the

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[23] Assuming there are N particles with positions Q_i, $i = 1, \dots, N$, then the k −th particle would evolve in time with a velocity given by $v_k = \frac{dQ_k}{dt} = \frac{\hbar}{m_k} \Im \frac{\psi^* \partial_k \psi}{\psi^* \psi}(Q_1, \dots, Q_N)$, where $\Im$ denotes the imaginary part, ψ is the Schrödinger evolving wave-function and m_k is traditionally intended mass of the k-th particle.

[24] One can in fact rewrite the guidance law of the particle as $v_j = W_j \Im \frac{\partial_k(\psi^* \psi)}{\psi^* \psi}(Q_1, \dots, Q_N)$, where $W_j = \frac{\hbar}{m_j}$ is the new constant, and $j = 1, .., n$, where n is the number or 'apparent families'. Similar considerations as the one I am providing here can be also found in Goldstein et al (2005).

[25] This theory was dubbed GRWp3 in Allori, Goldstein, Tumulka and Zanghí (2014) and in Allori (2019), while it is called GRWp in Allori (forthcoming).

[26] For particle k, the velocity is $v_k = \frac{dQ_k}{dt} = \frac{\hbar}{m_k} \Im \frac{\partial_k(\psi^*_{GRW} \psi_{GRW})}{\psi^*_{GRW} \psi_{GRW}}(Q_1, \dots, Q_N)$, where the wave-function evolves as in the GRW process but it collapses to a point centered where the particle is at that time and shifted at random.

[27] The effective laws is similar to the one in the pilot-wave theory : $v_j = W_j \Im \frac{\partial_k(\psi^*_{GRW} \psi_{GRW})}{\psi^*_{GRW} \psi_{GRW}}(Q_1, \dots, Q_N)$, $j = 1, .., n$, where n is the number or 'apparent families' of particles, $W_j = \frac{\hbar}{m_j}$ is the new constant, together with the rate per particle λ, and the wave-function width σ present in the GRW evolution. Notice that the wave-function in the law for the velocity will change at the time of collapse into the collapsed wave-function.

[28] This theory was originally proposed by Ghirardi , Benatti and Grassi (1995), and was dubbed GRWm in Allori et al. (2008).

[29] In formulas: $M^\psi(x,t) = m_1 \int dq_1, dq_2, dq_3\, \delta(q_1 - x)|\psi_{GRW}(q_1, q_2, q_3, t)|^2 + m_2 \int dq_1, dq_2, dq_3\, \delta(q_1 - x)|\psi_{GRW}(q_1, q_2, q_3, t)|^2 + m_3 \int dq_1, dq_2, dq_3\, \delta(q_3 - x)|\psi_{GRW}(q_1, q_2, q_3, t)|^2 = M_1^\psi(x,t) + M_2^\psi(x,t) + M_3^\psi(x,t)$. Visually, one has three distributions of matter: one, M_1, corresponding to the 'electrons' of 'mass' m_1; the other, M_2, corresponding to the 'protons' of 'mass' m_2, and the third, M_3, to the 'neutrons' of 'mass' m_3 , each centered around where one would think they are located, that is respectively q_1, q_2, q_3. This generalizes to N 'particles' as follows: $M(x,t) = \sum_{i=1}^N m_i \int dq_1, \dots . dq_N\, \delta(q_i - x)|\psi_{GRW}(q_1, \dots, q_N, t)|^2$.

wave-function, and as such it contains only one parameter: m_i.[30] Therefore, the effective law can be obtained by turning these parameters into constants.[31] Also in the case of the many-worlds theory, one could assume matter to be represented by the matter field like we have seen above but defined in terms of the Schrödinger evolving wave-function. This field inherits the superpositions of the wave-function, but since the various terms effectively do not interact they can be seen as describing different worlds superimposed in the same space-time.[32] The law of nature and the effective laws are defined similarly to the case of the spontaneous localization theory with matter density.[33] Moreover, symmetry properties help us guiding in the choice of the physical objects: in order to preserve symmetries, one has to deny that they are represented by the wave-function, as in the case of electromagnetic fields. In this context, indeed, it is even easier to deny the materiality of the wave-function, given that, in contrast with the electromagnetic fields, it is not even living on three-dimensional space. The best way to think of the wave-function in this context is as quasi-nomological, for the same reasons we gave for the fields in classical electrodynamics.

Now let us explain how my view provides a nice fit for wave-function realism as well. My proposal drops properties altogether, and pass on their explanatory role to the laws, which are now the true explanatory entities in that they govern the motion of fundamental stuff. As we discussed, both in the case of Albert and Ney, property talk is completely fictional: three-dimensional objects as we usually think of them are either functionally defined or symmetry-privileged 'shadows' of the wave-function, but no reference to their properties in the traditional sense is given or needed. In the case of Albert, what it is to be a system of three-dimensional objects is to have their behavior described by a given Hamiltonian. That is, to be a three-dimensional object is to have

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[30] So that, for an 'electron' with 'mass' m_1 it will be:
$M_1(x,t) = m_1 \int dq_1, \dots, dq_N\, \delta(q_1 - x)|\psi_{GRW}(q_1, \dots, q_N, t)|^2$.

[31] For completion, one could imagine the fundamental objects not to be in three-dimensional space, evolving in time, but to be directly located in four-dimensional space-time. In this way, there are certain events in space-time, that one can call 'flashes,' that are non-empty, so to speak, and they represent matter. This theory was initially proposed by Bell (1987), and then dubbed GRWf by Allori et al.(2008). Every flash (X, T) corresponds to one of the spontaneous localization of the wave-function, and its space-time location is just the space-time location of that collapse. Assuming there has been n collapses, the flashes will be the set $F_n = \{(X_1, T_1), \dots (X_k, T_k), \dots, (X_n, T_n)\}$, k being a progressive natural number indicating the time progression of the flashes. As one can see, the only property the flashes possess is their 'location' in space-time. Since T_k, X_k and n are random, the wave-function is also random. However, given the initial wave-function, the statistic of the future evolution of the flashes is determined. For simplicity reasons, I overlook the derivation of the effective laws in this case, which is however possible.

[32] This theory was proposed by Allori, Goldstein, Tumulka and Zanghí (2011), who argued that it may have been what Schrödinger had in mind when he first propose his wave equation.

[33] Explicitly, the law of nature is: $M(x,t) = \sum_{i=1}^{N} m_i \int dq_1, \dots . dq_N\, \delta(q_i - x)|\psi(q_1, \dots, q_N, t)|^2$, and the effective law for 'electrons' is: $M_1(x,t) = m_1 \int dq_1, \dots, dq_N\, \delta(q_1 - x)|\psi(q_1, \dots, q_N, t)|^2$.

one's behavior depending on changes in position and on inter-particle distances in three dimensions (Albert 1996, 2013, 2015). In the case of Ney, symmetries select three-dimensional objects as privileged, and three-dimensional entities exist derivationally as a partially instantiated by the fundamental high dimensional wave-function, where, again, no mention of fundamental or derivative properties is given or needed. Of course, there is a sense in which this approach is not a thin object-oriented metaphysics grounded on structure in the same way as the primitive ontology approach. In the classical theory and in the primitive ontology approach the continuity is greater: the thin objects are three-dimensional, and the structure is the set of the relations among them given by the wave-function. In the wave-function realist framework instead the situation seems to be as follows. First, the wave-function is what physical objects are made of, and it has no fundamental property other than its amplitude in each point of configuration space: thus it is itself a thin object. However, this is not the thin object one uses to explain our observations directly. Rather, they are accounted for in terms of the derivative three-dimensional objects given the structure provided by the wave-function. These three-dimensional objects are also thin: they have no fundamental property other than the fact that they are three-dimensional and localized somewhere. The approach is, in a sense, doubly structural: the structure of the wave-function allows for the derivative existence of three-dimensional objects, and it also explains their behavior. No such thing happens in the primitive ontology approach, given that the wave-function is not considered material. Finally however, at least in the case of Ney, symmetry help us select what the objects are, just like in the case of the primitive ontology approach, with the qualification that here these objects are derivative rather than fundamental.

4. Comparison

In the previous section I have presented an alternative view to the traditional metaphysics as grounded on properties. I have shown that an approach like mine, in which all fundamental entities are identical and guided by the same law can be explanatory of different behaviors under the same circumstances without invoking properties but making use of effective laws, is possible. In this section I argue that it is also preferable to the traditional view because it is simpler, more explanatory and more compatible with quantum theory, regardless of whether one is a wave-function realist or a proponent of the primitive ontology approach. I discuss some objection in section 4.2, before concluding in section 4.

4.1 Advantages of My View over the Traditional View

Presumably, one motivation for the traditional view is its simplicity: it is the most straightforward way of accounting for the behavior of the fundamental entities. Or isn't it? In fact in this account, most of the explanatory burden is carried by the properties.

However, as Esfeld (2014) has pointed out and as I briefly mentioned in section 2.1, we are far from having a satisfactory notion of categorical and dispositional property. In contrast, in my framework the entire debate over the nature of properties is completely eliminated: there are no fundamental properties other than spatio-temporal properties.

Moreover, my approach is ontologically more parsimonious than the traditional view. In the standard view, in addition to space-time, we have three categories: ontology, fundamental properties of the ontology, and laws of nature. Here we have only two: ontology, and laws of nature (loosely understood as structure). Since we have fewer categories to account for, Ockham's razor seems to favor the latter approach. Ockham's razor is the principle that, when presented with competing alternatives, one should select the one that makes the fewest assumptions. It is widely used in theory selection but notoriously difficult to justify.[34] Anyway, one could construct an optimistic meta-induction argument to support parsimony: my view postulates only one kind of stuff, and theories like that have been historically more successful than theories that have postulated more than one. Think for instance of ancient astronomy, biology pre-Darwinism, pre-genetic physiology: they respectively postulated the existence of ether to constitute the Heavens in addition to earth, of an Intelligent Designer to create the wonders of nature, and of an *Elan Vital* to account from the difference between living and death things. Now we know that we do not need to postulate these additional kinds in order to satisfactorily account for the evidence. In fact, more empirically adequate theories have each an ontology which is more parsimonious: respectively, Newton's theory of gravitation, the theory of natural selection, and modern physiology. Therefore, it is likely that the traditional approach, which postulates more categories of entities than mine, is false too.

One could think that, from a Humean perspective with respect to laws, the claim that my approach is more parsimonious is unwarranted, as Humeans conceive of laws not as ontological additions. Even so, however, my view seems to be the natural extension of Humeanism, since it provides a better best system.[35] In the context of the Humean account, in which laws are theorems and axioms of the best system, my view provides a better combination of simplicity and strength. In fact, to have laws and effective laws does not change the situation from the traditional picture: theorems are the same and so are the axioms; the only thing that changes is that some parameters are now constants. On the other hand, there is only one kind of matter, rather than many. In the context of a necessitarian, or a primitivist account, the case may be not so compelling, but one could use the instead parsimony argument to argue my view is to be preferred. In any case, two things should be noted: one does not have to take a stand on the nature of laws to hold my view, and in any case laws are mysterious things, and

[34] See Sober (2015) for some history and some means of evaluating parsimony based reasoning.
[35] See also Esfeld (2014).

in my approach one is pushing all the mysteries in one place (the laws, intended as structure) instead of two (laws *and* properties).

My view may also be compatible with Humean supervenience as long as the objects have as fundamental properties the only ones that specify their nature and that symmetry constraints allow generating the laws from the objects. Humean supervenience is the doctrine that all the facts about the world supervene on the distribution of fundamental properties of points in three-dimensional space. However, in wave-function realism, the locality condition in the definition of Humean supervenience (namely that there are properties for each point) does not hold. The wave-function is a nonlocal object, in fact by definition it is a function of the 'particle' configurations: $\psi(x_1, \cdots, x_N)$. Therefore, the particle's motion, though the wave-function, will be influenced by other particles far away. Because of this nonlocality, Teller (1986) argued that Humean supervenience is false, and further criticisms followed.[36] Nonetheless, some proponents of wave-function realism like Loewer (1996) and Ney (forthcoming) modify the Humean supervenience thesis to be formulated in configuration space, so that the theory is local in configuration space. This is perfectly compatible with my view: in the case of wave-function realism one is naturally led to see the Humean supervenience thesis as formulated in configuration space, and then one needs to explain how it grounds the fact that for the derivative three-dimensional objects locality fail. Moreover, in the primitive ontology framework, the wave-function is not a physical entity but merely a part of the law. Assuming that enforcing symmetry constraints allows to select one law of nature over the infinite other possibilities, one can argue that the wave-function supervenes on the local matter of facts given by the thin objects.[37] Similar considerations however do not seem to hold also for wave-function realism, given that the wave-function represents what is fundamental, and the thin objects are derivative.

A clarification regarding parsimony: 'less is more' as long as one is able to satisfactorily explain. So, one could complain that even granting that my view is more parsimonious than the alternative it is less explanatory. However, I argue, my view turns out to be more explanatory than the traditional view. In fact, it has less things to account for. One of the main problems of the Standard Model is that it cannot explain why particles have they mass they do. Why does the proton and the electron have masses in the particular relation we observe? My view eliminates the mystery because there are no masses or charges, but merely objects and structure (laws and effective laws). One could complain that the situation has not changed since we have no explanation of why different effective laws exist and why they apply as they do. Nonetheless, I think this is not quite true: we do not know why the laws are what they

[36] See for instance Maudlin (2007), Ladyman and Ross (2007), Esfeld (2009), French (2014).

[37] This is similar to what Esfeld (2014) calls 'super-Humeanism.'

are anyway, and in the traditional view, we *also* do not know why particles have the properties they do. In my view instead, we do not need to explain things about matter, we 'just' need to explain things about laws. And as I suggested already in section 4.1, laws may be generated by symmetry constraints over the laws as well as assuming simplicity as a guide to theory choice.

In addition, this approach also seems to be compatible with the fact that in relativity theory the mass changes with velocity. One could say that the rest mass, the one that does not change with velocity, is the property. Still, she would have to explain what the other portion of the mass is. Instead, if mass is not a property, we have no puzzle whatsoever.

Also, in the framework of classical electrodynamics, my account makes sense of certain asymmetries between particles and fields. The first asymmetry that comes to mind is that particles have properties and fields do not. However, why is it that one can have particles with different masses and charges, but only one filed (the electromagnetic field)? In my approach, there is no problem: one particle type, no properties, and no fields. Moreover, particles generate fields, but fields do not generate particles. Then, the fields act on the particles in virtue of the particles' properties, however, particles do not act on fields in virtue of the field's 'properties' (since they haven't got any). In my approach, these puzzles disappears because there are no fields.[38]

Even if this consideration would not apply to wave-function realism, one could point put that my view could appeal to the more empiricist minded philosopher or scientist. In fact, to distinguish a proton from an electron we look at its track in the bubble chamber (or in the fancier, more modern version of it), and we see it curve one way rather than another: we measure its trajectory, not its mass or charge. *The only thing we see is stuff that moves*: we see positions that change; we do not see masses, charges, or spin. Thus, from a point of view in which one attributes reality to what is observed, this is the natural ontology, this is what we should take seriously: locations.

Perhaps more strikingly, the fact that in this approach there are no other properties than the spatio-temporal ones makes contextuality in quantum mechanics go away. A more detailed discussion is probably needed, however let me note the following. In quantum mechanics 'spin' has usually been considered as a paradigmatic

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[38] Somewhat similarly, a common objection to the pilot-wave theory is that the wave-function acts on the particles but the particles do not act on the wave-function. One can respond to this objection easily from the point of view of the primitive ontology approach by pointing out that the wave-function is nomological: it acts on the particles as a law of nature would, and matter do not 'act' on the law. Form the point of view of wave-function realism, instead, there is no straightforward answer, which presumably means that this framework is not a good fit for the pilot-wave theory. Indeed, someone motivated to have the local and separable ontology arguably provided by wave-function realism would not tend to consider this theory as satisfactory.

quantum property. However, it turns out that this property is contextual: its value depends on the experiment made to reveal it. That is, the values of the spin of a particle changes depending on whether it is measured together with one property or another. It is as if the value of the length of a square table when measured together with the weight of the table would be different from the value obtained when the length is measured together with the height. This is a serious problem for someone who thinks spin is a property: what kind of fundamental, intrinsic property changes its value like that? This kind of considerations have led many to think of spin as another example of the paradoxical nature of quantum mechanics, and spent oceans of ink to speculate about its possible meanings.[39] Instead, if we follow the approach proposed here, there is no mystery left: spin is not a property; spin is part of the law of nature that governs the motion of matter. The fact that its value changes depending on the way in which it is 'measured'[40], is merely a consequence of the fact that experimental apparatuses can affect the system in ways that may destroy a 'property' one is trying to reveal. That is, if we measure a table's length by taking its legs apart and then comparing the size of the flat surface to another of known value, and then we measure its height afterwards, we find that it is very different from what we would have found had we measured it before disassembling the table. So, there is no mystery about contextuality and spin is not a property.[41] Therefore, as we saw previously, the primitive ontology approach is compatible with the traditional view. However, as we just saw, if one wants to keep this approach will end up with contextual properties, which are undesirable. What does it even mean that a property is contextual? If it is a property, it is some feature of the object, and not of the context. Therefore, I argue, one should endorse my view, which would make contextuality disappear. In wave-function realism, as we discussed previously, we were already departing from the traditional view given the fictional role of properties in this framework. Now, we are simply pointing out an additional reason to abandon the traditional view: if we keep the traditional framework our 'property talk, ' which could so far be motivated for being familiar, simple, and informative, would now become far-fetched, convoluted, and non-explanatory. Because of this, property talk loses its only purpose in the approach, and thus, has no reason to be. So, no matter which your favorite quantum metaphysics is, my approach is more compatible with it than the traditional view.

4.2 Possible Objections to My View

First, one could complain that this view is unnecessarily radical and revisionary: why someone would want to get rid of properties if they work so well in the standard

[39] See for instance Mermin (1993).

[40] The scary quotes indicate that nothing is truly measured here.

[41] See Daumner et al (1996) for more on this point.

schema? My reply is that the proposal is far from being unnecessary: properties are notoriously rough nuts to crack and, as already mentioned, there are severe problems in trying to spell out what fundamental properties are. Also, as noted in the previous, my view has several advantages over the traditional core, which makes it at least worth exploring: it is compatible with Humean supervenience; it extends smoothly to the quantum domain; it is more explanatory and simpler.

Similarly, someone may think that asserting that there are no fields in classical electrodynamics or in general asserting that there are no properties is contrary to our intuitions and our ordinary beliefs. That is, this approach makes many of our beliefs false, and theories like that are not to be favored, all things being equal. However, one could respond by rejecting such a criterion, or maintaining that all things are not equal. After all, many of the modern scientific theories ask us to revise many of our ordinary beliefs, but we do not reject them because of it. In fact they provide explanatory insight, and they are more empirically adequate than out ordinary beliefs. Our ordinary belief is that matter is continuous, but we are mistaken because atomic theory, which is more explanatory and empirically adequate than our ordinary beliefs, teaches that it is mostly void. Similarly, our ordinary belief is that fields exists and that properties exist, but we are mistaken because my approach, which is more explanatory and empirically adequate than our ordinary beliefs, teaches that this is not the case.

In addition, one may think that in my view there are infinitely many laws, one law for every massive object, and this makes the claim that my view is more parsimonious mistaken. Nonetheless, this claim not accurate: not one law for every massive object, but one law for every entity that in the traditional view we take to be fundamental. In my approach, there is just one kind of material entity, and one kind of law. Laws are implemented differently depending on what they are acting on. If one thinks structurally, the law and the effective laws are the network of relations between the fundamental objects. Macroscopic objects are made of the microscopic entities, and their behavior can be explained and accounted for in terms of them. Once we discuss the situation at the microscopic level, in the standard view we have, say, N fundamental particles identified by their fundamental properties (masses, for instance) and one law of nature; here we have one kind of particles, and N effective laws. Or, better, one kind of particle and a more complex structure.

Another worry could be that it is mysterious how different effective laws act on matter, if there is just one kind. The traditional idea is that the positive charge of the proton makes it go down rather than up in a given magnetic fields. In the view proposed here instead we have just matter. So, how is a material entity 'paired up' with its effective law? To respond, notice that in the traditional view it is a primitive fact that positive charge will result in 'going up' in a given magnetic field. In contrast, here it is a primitive fact that that effective laws act as they do on the various material entities. That is, every view needs to have primitives: in the traditional approach, fundamental properties are primitive; here it is the pairing between objects and their effective laws, or, if one wishes, to the thin objects and the structure. Instead of focusing on laws and effective laws, think about what they truly are: a structural network of relations that determines how matter moves. One may complain that not all primitive postulates are on the same footing and that mine are more radical. If so, we have to agree to disagree on that: the use of properties as in the traditional approach to explain the particle behavior just looks like magic to me. What is mass? Where is it? How does the law act on the particle mass and modifies its behavior? One does not ask these questions in my account but the last one: how does the law 'hook up' with the particle and modify its behavior?

Another related objection may be expressed by this question: what characterizes the difference between empty points and material points? The response of the traditional view, namely that they are massive points, is of course unavailable to me. However, I wonder whether this is even a satisfactory response, given that it is mysterious what masses are. In any case one could reply that, whatever masses are, they are something, while I have nothing. Nonetheless that's not true, as I can indeed claim the same. In fact I can say that there is a primitive distinction between space points: those that are full of matter and those that are not, and the former change their location in time according to the laws.

One could think of other more technical problems. For instance, one could think that the relation $E = mc^2$, which establishes that the energy of the particle is associated to its mass, cannot fit in this approach because if mass is not a property, so energy is not a property, and that is wrong. However, there is nothing wrong in this, and neither there are tragic consequences if energy turns out not to be a property. We are used to think of mass as a property, but we are mistaken; similarly, we are used to think of energy as a property, and we are mistaken as well.

5. Conclusion

In this paper, I have described a view that provides an alternative account to the traditional way in which naturalized metaphysicians use to explain the behavior of physical objects. While the traditional view is in terms of laws of nature which guide objects in theory motion, and in which properties such as mass or charge play a fundamental role in the explanatory schema, I have proposed a view in which fundamental objects are without any fundamental property other than the one(s) which allow to determine its nature. While in the traditional view, there are families of particles, divided in virtue of the different properties these particles possess, in my account all matter is identical. The explanation of why two objects behave differently in the same situation is not given in terms of them having different properties. Rather it is provided by the fact that they obey different effective laws, namely different variants of the same fundamental law of nature which encode what we traditionally call properties.

So, if in the traditional picture an electron going up in a magnetic field as opposed to a proton going down is explained by invoking that they have opposite charges, in my view there is no such different between an electron and a proton: they are two particles which are however guided by different effective laws. This view can be dubbed a thin-oriented metaphysics grounded on structure as opposed to the traditional view which could be called an object-oriented metaphysics grounded on properties. In fact in my approach objects are 'bare' or 'thin,' given that they have no fundamental property, and it is a structuralist view insofar as the effective laws provide structural relations between the fundamental objects. Also, symmetries are important, as they play an important role in selecting the ontology as well as the law of nature. I have argued that my view is more explanatory and simpler than the traditional account, that it is more compatible with quantum theory and Humean supervenience. In particular I have argued that in the quantum domain this is the best approach to metaphysics regardless of one endorsing the primitive ontology framework or wave-function realism.

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