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TROPES AND PHYSICS

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Summary

This paper looks at quantum theory and the Standard Model of elementary particles with a view to suggesting a detailed empirical implementation of trope ontology in harmony with our best physics.

Introduction

According to some (see Bacon (2002)), the notion of a *trope*—that is, of an 'abstract particular', or 'particularized property', not deriving from a universal—can be traced, among others, to Plato, Aristotle, Boethius, Avicenna, Saint Thomas, Scotus, Leibniz and Husserl. For sure, it was defended in the 20th century by Stout (1921) and (1923), and later by Williams (1953). Nowadays, the literature on tropes is becoming progressively larger (see, for instance, Campbell (1981) and (1990), Simons (1994), Daly (1994), Denkel (1996) and (1997), Von Wachter (2000), Chrudziminski (2002), Maurin (2002) and Stjernberg (2003)). Despite a growing popularity of the theory[1], though, an evident gap persists as regards the *application* of trope ontology; in particular, while the amount of work specifying how the view is to be understood—or what is (allegedly) wrong with tropes—is by now sizeable, few authors have attempted to substantiate the claim that the basic constituents of reality are tropes by identifying the latter with actual entities described by physical theory. Metaphysics, though, had better mesh well with our best scientific theories; whence it is clear that there is a missing brick in the philosophical construction here. This paper aims to fill this gap by looking at quantum theory and the Standard Model of elementary particles in search for the

1. Not all the mentioned works are in favour of tropes, but their number is in any case a proof of the increase in interest in trope ontology.

basic tropes. It critically analyses existing proposals based on the concept of a field-trope (Campbell (1990) and Von Wachter (2000)); and elaborates upon the 'nuclear theory' formulated by Simons (1994).

In Section 1, a few preliminary remarks on trope theory are made. Section 2 looks at the work of Campbell and Von Wachter and points out problems besetting field-trope-theoretic ontologies; and then takes into account Simons' view, identifying its merits and the ways in which it can be improved upon. Section 3 offers a specific suggestion as to what tropes should be regarded as fundamental, and how they make up reality. Section 4 adds some observations concerning quantum properties and emergence. A concluding section summarises the arguments of the paper.

1. *A few remarks about tropes*

In a nutshell, trope theory is the ontological view that reality is constituted by so-called *abstract particulars*[2] grouped together in complex concrete particulars. Economic and simple as it is, this perspective historically had to face a number of criticisms. As a nominalist theory dispensing with properties as repeatable universals, trope ontology must first of all explain *similarity*, which, so to speak, 'comes for free' if one subscribes to realism about universals. Normally, the trope ontologist argues that an explanation of resemblance facts does not require a commitment to the existence of additional entities (in particular, reified resemblance relations)[3] over and above the similar entities; and that, instead, a particular *a* resembles another particular *b* exclusively in virtue of *a* and *b*. Basically, the claim is that tropes have their qualitative nature essentially and, therefore, as soon as they exist their 'causal role' in the world is determined and so is, as a consequence, whether such role is the same for any two of them. Von Wachter (2000) rightly points out that this is something that the bundle theorist who is a realist about universals must also accept, insofar as non-exact resemblances are concerned. For, the multiple instantiability of universals can only explain

2. The *abstractness* of tropes is not to be thought as in opposition to the *concreteness* of actual particulars. As we will see, tropes are best regarded as fundamental material constituents. Rather, talk of tropes being abstract points to the fact that they can only be individuated by 'abstracting' them from the complexes they are parts of. We will see, on the other hand, that it is at least conceivable that certain basic tropes can exist on their own.

3. As argued by Russell (1912, ch. 9), this is likely to give rise to an infinite regress of resemblance relations.

the exact similarity between instances of the same universals, but less than exact resemblances must be accounted for in terms of resemblances among numerically distinct universals.[4] Hence, the trope ontologist's typical claim of primitiveness appears plausible as far as similarity is concerned.

Something must also be said by the trope ontologist with respect to the way in which tropes constitute complex particulars. Initially, compresence was taken to be sufficient (for example, by Williams (1953)). However, it was soon pointed out that something more is needed. First, if compresence is regarded as an external relation additional to the compresent tropes, it seems that a form of vicious regress cannot be avoided. Suppose that, in the spirit of trope nominalism, one tries to explain the compresence of two tropes by referring to tropes only and consequently regards compresence relations as additional, genuine tropes. This means to say that trope *t* and trope *u* are compresent because of a third trope *c* that causes them to be so. But then one has to explain the relation between *t* and *c*, and that between *u* and *c*, in turn. And further tropes must be postulated. It is easy to see that this gives rise to an infinite regress similar, for instance, to that pointed out by Aristotle in his 'third man' argument against Plato's Forms. Daly (1994, 258–260) argues that the problem can only be avoided by positing a primitive instantiation relation among the compresent tropes on the one hand and the relational compresence tropes on the other, but this is an unwelcome result, as to acknowledge the primitiveness of instantiation naturally leads to the endorsement of an ontology with *substrata* (which are *defined* as the entities that instantiate properties and relations). Secondly, and much more generally, compresence does not appear sufficient to ground the internal unity of concrete particulars: neither conceptually (are overlapping distinct trope complexes impossible?), nor in practice (think of the possibility, supported by contemporary physics, of numerically distinct but entirely compresent concrete particulars).

The best trope-theoretic approach to this problem seems to be the following. The nature of compresence must, first of all, be distinguished

4. Rodriguez-Pereyra's resemblance nominalist ontology is also based on the claim (2002, 115) that the truth-makers of '*a* and *b* resemble each other' (R) are just *a* and *b*, and therefore the existence of *a* and *b* is sufficient for the truth of R. However, there is an important difference: resemblance nominalism is based upon the idea that the *joint* existence of two (concrete) particulars determines the truth of claims regarding the resemblance among these particulars and, *consequently*, of claims about the properties they exemplify. On the trope-theoretic construal, instead, each trope *by itself* is the truth-maker for claims regarding property-ascriptions involving it and, *as a consequence*, for claims regarding (dis)similarities between it and other tropes (and between the complex particular that trope is part of and other complex particulars).

from the question of how simple tropes give rise to complex particulars. With respect to the former, similarly to what was said about resemblances among tropes, again one can endorse a simple 'deflationary' position, and regard the relation of compresence as supervenient on facts about the existence of the relata and not vice versa. As for the dynamics according to which simple tropes give rise to complexes provided with inner unity and cohesion, instead, it is best accounted for on the basis of *internal relations* independent of the tropes' locations. The first suggestion in this sense was made by Simons (1994) with his 'nuclear theory' of tropes. According to Simons, we must conceive of internal cohesive relations among coexisting tropes as Husserlian *foundation relations.* Husserl (1911–1917 (1970)) maintained that an entity *t* is *founded* on another entity *s* if *s*'s existence is necessary for *t*'s existence; and *s* and *t* are *directly foundationally related* if and only if each one of them is founded on the other. Tropes, Simons claims, can be such that, given a collection of them, each one is foundationally related to every other in the collection and nothing else. Bundles of such tropes are called *foundational systems* by Simons, and he presents such systems as the fundamental entities of reality. Simons, in particular, takes nuclei (or 'kernels') of mutually foundationally related tropes to constitute substrata to which peripheral layers of tropes become attached. While the nucleus constitutes the essential 'core' of each individual bundle of tropes and does not change, peripheral tropes can be lost, added and replaced. Simons' account, then, explains how complex particulars are constituted by exclusively invoking relations of mutual existential dependence that do not require additional entities beyond the basic tropes.

As pointed out by Denkel (1997), though, this framework is unable to provide room for *substantial* change, that is, for the type of change that involves the partial or total loss of an object's essence. For, such a change would require a modification in an entity's nucleus. But, the tropes composing the latter being existentially dependent on each other, the identity of the entity in question is *dependent* on *all and exactly those* tropes; and would therefore not persist after such a modification. Consequently, any conceivable change of *that* entity can only concern the external tropes 'added' to the nucleus. However it looks as though there are cases of substantial change. An example might be the decay of a type of particle into one or more particles of other types, typically described by elementary particle physics. Denkel says that situations such as this one

> are situations in which the so-called kernel of the object changes (or is lost) without the peripheral layer of contingent properties being lost, and it is hard

> to understand how Simons' theory, which endows essences with the function of a substratum, will permit such a thing (ibid., 601).

Denkel replaces Simons' foundation relation with a relation, which he calls a *saturation relation*, based on a weaker sort of necessity. Simons' (Husserl's) foundation relations are such that they render certain *specific tropes* necessarily internally related to (i.e., existentially dependent on) each other. According to Denkel's view, instead, compresent tropes constitute a complex particular provided with a specific identity only as *determinates* (specific realizations, such as 'weighing 5 kg') for certain *determinables* (generic properties, such as 'having weight …'). That is, coexisting tropes 'complete each other's existence', as it were, only as tropes of a certain *kind*, and not because they are exactly *those* tropes. It follows that *any* change is permitted (does not affect, that is, the identity and unity of the particular it involves) that can be accounted for in terms of substitution of a trope with another trope which acts as determinate for the same determinable.

In the light of the foregoing, it looks as though trope ontology can be convincingly defended by appropriately articulating its basic claim that similarity and compresence are primitives. But a few other things must be said. First, it seems that properties are best understood from the perspective of a *sparse* conception of properties, according to which not all predicates correspond to actual properties. Following the 'scientific' approach to sparseness endorsed by Armstrong (1978), in particular, this implies here that it is necessary to look at physical theory in order to identify what should count as a basic trope. It is important to notice that this, among other things, may turn out to be relevant with respect to a traditional objection to trope theory: namely, that tropes cannot possibly be fundamental constituents of reality, because—as specific property instances—they are *in principle* dependent entities. This objection is voiced, for instance, in Lowe's claim that

> [tropes] lack the fully determinate identity conditions characteristic of objects proper [… because they are …] *adjectival* rather than *objectual* in nature (1998, 156).

While this is indeed the case for certain properties (for instance, shape or colour properties), which clearly depend on their subjects for their existence and identity (could a shape trope exist on its own?), it is possible to claim that this is not true for all properties, and that those that escape the difficulty are exactly those tropes that should be regarded as the basic 'building blocks' on the existence of which everything else actually depends. The arguments in the following sections will indeed be aimed to confirm the plausibility of a presupposition to this effect.

Another alleged difficulty regards the simplicity of tropes. Some authors (for example, Mertz (1996), Moreland (1985), Hochberg (2004) and Armstrong (2005)) have argued that the trope ontologist is forced to claim that each trope has (at least) two aspects—one that makes it resemble other tropes (its nature), and another that makes it the abstract particular it is (its primitive particularity); and that this renders the theory inconsistent, as an internal complexity is acknowledged in the entity that was instead presented as a basic simple 'building block' of reality. Put in terms of truth-making, the same trope(s) can make logically independent propositions such as "*a* and *b* are exactly similar" and "*a* and *b* are numerically distinct" simultaneously true. And this means that each trope must be a complex entity. To this, it can be replied that, first, if one accepts (as, for one, Armstrong himself does in his paper) that truth-making theory by no means requires a 1-to-1 correlation between truths and truth-makers, there is no need to see trope ontology weakened in any way by the fact that many things can be truthfully said of one single trope. If it is possible for a simple entity to be a truth-maker for a number of truths, then ontological arguments must be provided against the simplicity of tropes. Secondly, though, at the ontological level it can be maintained that a trope has two 'aspects', and perhaps even more if we consider the entirety of its metaphysical features, but all these aspects are *numerically identical*: that is, that it is by just being the simple entity it is that a trope counts as one, is similar to other tropes in its nature, is distinct from other entities, affects and interacts with other tropes, and so on. On this construal, it is a mistake to take each one of a trope's aspects to be a distinct metaphysical component, for they are distinguished numerically from each other merely by conceptual analysis. Tropes, that is, are ontologically simple units, provided with primitive thisness[5] as a metaphysical feature which is not an addition to their 'empirical content'.

2. *Existing applied trope ontologies*

Having defined what appears to be the most plausible trope-theoretic account of reality, let us now move to the issue concerning what the basic tropes could look like in the actual world.

5. See Adams (1979).

Attempts to say something in this direction have been made by Campbell (1990), Simons (1994) and Von Wachter (2000), and these works indeed constitute a fundamental starting point.

These authors share the abovementioned idea that not all predicates correspond to real properties, and that what tropes actually exist must be established with the help of natural science (that is, they agree on the need for a sparse account of properties, and on the usefulness of Armstrong's 'scientific realist' approach to reality). However, they differ as to the actual entities they identify as fundamental tropes under this assumption.

Campbell (1990, ch. 6) suggests taking physical *fields* as the basic tropes. He considers this option independently appealing because in harmony with the developments of physical science. But he also takes it to represent a useful hypothesis in the context of trope theory because it makes it possible to deal with certain problems such an ontological view is usually taken to meet with. Campbell says:

> Taking our clue from space-time […], we now propose that all the basic tropes are partless and edgeless in the ways that space is, and that they change only in space-time's innocent way. All basic tropes are space-filling fields, each one of them distributes some quantity, in perhaps varying intensities, across all of space-time (ibid., 146).

In particular, Campbell takes it that there exists a field for each one of the basic forces in nature, plus one matter field and one space-time field. And he supposes that the varying intensities of the fields and their combinations give rise to the whole of reality. According to Campbell this allows one to deal with the *boundary problem* (ibid., esp. 136–141), consisting of the fact that tropes—despite their being taken to be fundamental constituents—appear to be divisible into other tropes of the same type. The problem is readily solved, he argues, because field-tropes are basic and indivisible. The problem of explaining the *compresence* of tropes and their constituting the same entity, Campbell adds, is also solved, because each field is endless and necessarily compresent with space-time at all points. The compresence of field-parts becomes therefore an internal relation and, as such, does not require an explanation.

Campbell's proposal is surely interesting but, nevertheless, it faces some problems.

First, it is simply not true that a field must be compresent with the whole of space-time: already in classical field theory there exists the possibility for fields not to be present at certain points of space-time. But suppose this problem is overcome, for instance by postulating that the basic fields are indeed extended across the entirety of space-time but have (or may have) intensity zero at some points. The true difficulty regards whether Campbell's 'field tropes' can truly be regarded as tropes.

Campbell speaks of extended fields with varying intensities at various points of space (which is indeed the canonical formulation of physical fields). But insisting on the seemingly plausible demand that one only posit as basic in one's ontology entities that are simple (which appears endorsed by Campbell when he talks of field-tropes as 'partless'), one could claim that this requirement is not met by extended entities with varying 'intensities' at different points. One could go as far as to suggest that Campbell's field-tropes are nothing but traditional substances with properties, on the basis of the fact that the different intensities of the same field must be similar or dissimilar to some extent and these (dis-)similarities should be explained in the terms of the ontology being put forward: namely, in terms of resembling tropes. But then one has in fact complex particulars with tropes as simpler components. Without going as far as talking of substances, at any rate, it suffices to point out that fields as Campbell describes them hardly seem to be basic simples upon scrutiny.[6]

Similar criticisms can be formulated against Von Wachter (2000), whose proposal has perhaps slightly different motivations and fine-grained features, but runs along general lines very akin to Campbell's. Von Wachter starts from the consideration that common sense properties do not have definite boundaries and, instead, constitute a continuum. On the basis of this, he postulates basic unitary and ubiquitous fields on which all those that we take to be properties are derivative.[7]

Here too, the complex array of qualitative aspects that is said to arise from fields appears to point to a tension between the basic intuition of trope ontology—that is, that certain particulars are the basic constituents of everything and, as such, must be simple—and the specific suggestion being put forward as to the identity of the basic tropes. Von Wachter's claim that the field intensities are *determinates* and the fields *determinables* further strengthens the feeling that what is really basic is something simpler than

6. It must also be pointed out that Campbell is instrumentalist about spin because he takes it to be a property that does not "pick out causal characteristics" (ibid., 149). Given the relevance of spins in the description of what particles actually do, this appears contentious. On the other hand, this is certainly not fatal to Campbell's ontological account.

7. In particular, Von Wachter argues that all properties correspond to either constant field intensities or to changes in these intensities, or to integrals over field intensities.

the entire field. How can a determin*able* be a fundamental component of reality in its actuality?

Given the above, it seems advisable to follow an alternative route, first suggested by Simons in connection to his above mentioned 'nuclear theory' of tropes (Simons 1994). According to Simons, we should look for basic tropes at the level of fundamental particles. Fundamental particles, he says, are entities with kernels constituted by

> a number of nuclear or essential properties like rest mass, charge, and quantum of spin [… and outer layers of …] contingent properties, e.g. their relative position, kinetic energy, momentum, direction of spin (all *at a time*) and so on (ibid., 570).

It is these properties, described by physical theory, that according to Simons we should regard as tropes. Simons' position is indeed attractive and—I believe—goes some way in the right direction, especially because it posits as basic tropes elements that indeed appear as fundamental and simple, and are so described by our best science. However, it too remains insufficient.

The basic reason for this claim is that Simons overtly acknowledges his perplexity as to how exactly to deal with quantum properties (in particular, as regards the fact that some of them are described via probabilities, and allow for superposition of multiple values (ibid., 573–574)), and warily leaves the definition of the fundamental tropes vague. Also, although less importantly, Simons' account of indistinguishable bosons seems unconvincing from a trope-theoretic perspective. He suggests that in the case of many-particle systems of identical bosons

> [p]erhaps what happens is that two or more trope packages, when they get into proximity, expire […] in favor of a single trope package whose properties are not really, but only apparently inherited from their predecessors (ibid.; 573).

This is based on well-known facts concerning the indiscernibility of bosons. However, it is unclear why the trope theorist should subscribe to such a view, especially in the form according to which the new 'package' is composed of distinct tropes from those of its components. Simons appears here not to fully appreciate the fact that one of the advantages of the trope theory he endorses (in particular, with respect to the bundle theory, committed to the Identity of the Indiscernibles) is exactly that it allows one to avoid certain ontological conclusions that are often drawn about the identity of things.

What can be done to improve on Simons' proposal? In what follows, I offer an answer to this question.

3. *Tropes, entity constitution and the Standard Model*

The hypothesis that is taken nowadays to be the best available description of the basic constituents of reality and their interactions is the so-called *Standard Model*.[8] Such a model was developed in the early 1970s in order to account for three of the four known fundamental interactions among elementary particles (with the exception of gravity, which is still not treated adequately by microphysics). To date, it has had an impressive series of experimental confirmations. In particular, it successfully predicted the existence of a number of particles (such as the top quark) before their actual observation, and the actual values of several quantities (e.g., the mass of the W boson).[9]

According to the Standard Model, the fundamental particles are 12 fermions constituting matter and 12 bosons mediating forces.[10] Fermions can be either *quarks* (six types, or 'flavours') or *leptons* (six more flavours). Bosons comprise *photons*, W^+, W^- and Z^0 *gauge bosons*, and eight *gluons*. Each type of particle carries *charges* determining their interactions. Each fermion has a corresponding antiparticle, identical to it except for the fact that it has opposite electric charge (and, in the case of quarks, colour).[11] Each boson-type constitutes instead its own antiparticle, with the exception of the W^+ and W^- bosons, which are each other's antiparticle.

8. For a detailed treatment of the Standard Model, see Kane (1987).

9. On the other hand, the Standard Model does have shortcomings: it has a high number of free parameters; it conflicts with the cosmological hypothesis of the Big Bang in certain respects (matter/antimatter ratio, initial cosmic inflation); and it predicts the existence of a particle (the Higgs boson) which has not been observed yet. At any rate, the Standard Model remains the best model for a description of the elementary constituents of reality that we have available.

10. In actual fact, they are more, but I am referring here only to the actually detected particle-types, ignoring both Higgs bosons and gravitons (which are not even an integral part of the model).

11. Note, however, that neutrinos only have mass, and so cannot be distinguished from the corresponding antiparticles on the basis of this criterion. While it is possible to say that neutrinos have left-handed and antineutrinos right-handed *chirality* (that is, projection of the angular momentum to the direction of motion), some suggest that they are the same family of particles, much like in the case of electrically neutral bosons. Neutrinos and antineutrinos are indeed sometimes referred to as a whole as 'Majorana particles'. This, however, does not affect the arguments that follow.

Let us, then, look at the *properties* of these entities (ignoring, for simplicity, antiparticles). Most particles (all except gluons and photons) have inertial *mass*. Each quark has any of three '*colour*' charges ('red', 'green' or 'blue') enabling it to take part in strong interactions, that is, to constitute protons and neutrons. All quarks also have *electric* charge, and so participate in electromagnetic interactions as well. Leptons do not have colour charge, and so do not take part in strong interactions (they do experience, however, the weak force and—if electrically charged—the electromagnetic force). W^+, W^- and Z^0 gauge bosons mediate the weak nuclear interactions, the first two having mass and electric charge, while the third only mass. The gluons are mass-less and electrically neutral, but carry colour charge, in virtue of which they interact among themselves and bind quarks together into protons and neutrons.[12] Photons, the particles making up all forms of light and responsible for electromagnetic phenomena, do not seem to have any of these properties (or any other property, for that matter). However, each photon possesses *energy*, and this entails that it can in fact be attributed *relativistic* mass. True, the latter is distinct from the masses of the other types of particles, as those are *invariant* masses. Nevertheless, the difference is one of 'form' rather than 'substance': as is well-known, according to relativity theory energy and mass are two 'aspects' of the same thing. Hence, I take it that tropes from the same 'family' can be attributed to photons and to the other particles as their 'masses'. It thus looks as though—according to the model we are adopting as the most credible hypothesis—all known particles have at least one of three possible properties: mass, colour and electric charge (and, in most cases, they have both mass and electric charge). These I suggest to take as the fundamental components of reality.

Are there any other properties to be considered?

Certain properties normally associated with particles and explicitly mentioned, as we have seen, by Simons—such as, for instance, momentum—are in fact excluded from the Standard Model. This seems justified on the basis that these properties are not essential for the material constitution of the particles. In fact, they are not even 'concrete', and just describe the particles' dynamic behaviour. Space(-time) location, for example, expresses the relation between a trope (or trope-bundle) and other tropes (or bundles)—or between tropes and space-time points—and by no means needs to be reified.

12. In particular, they can be thought of as having both colour and anti-colour (the property of the antiparticles of quarks corresponding to the quarks' colour), and their number is directly derivable from the mathematical structure of the theory of strong interactions, quantum chromodynamics.

On the other hand, all particles are commonly said—on the basis of the Standard Model itself—to possess spin as an essential property. Fermions have spin ½, while bosons have spin 1. However, the actual spin (in one of three possible directions) for each particle can assume one of two values (±½ or ±1) and, consequently, only the absolute spin magnitude is fixed for each particle type. This is what Simons has in mind when he distinguishes 'quantum of spin' and 'direction of spin', and takes the former to be an essential property and the latter as a contingent property. However, it seems incorrect to talk of two properties here, for there is only one spin observable (along each direction) for each quantum particle.

It seems to me that this requires a peculiar treatment of spin along the following lines.

In general, in quantum mechanics a specific value for a state-dependent observable can be possessed with probability p such that $0 \le p \le 1$. In such cases, the system is in a so-called 'superposition' of several values for that observable, each one attributed a probability. This is what happens for spin. It looks as though observables of this type can be understood in one of two ways: either as 'fuzzy' properties that can fail to have a definite value unless measured, in which case spin should be understood as an actual trope that can possess 'unsharp' values. Or as *dispositions* that probabilistically determine future measurement outcomes, in which case superposition—say, of spin values—can be regarded as coinciding with the different probability assignments 'encoded' in the disposition. I favour the dispositional account, and take it that spin is normally (unless, that is, it comes to be possessed as a 'categorical' property in virtue of a measurement) a dispositional property (or 'propensity'). Following Suarez (2007), in particular, I conceive of quantum dispositional properties as weighted sums of projectors corresponding to the system's eigenstates for the observable in question. Technically speaking, if Q is a discrete observable for the system Ψ with spectral decomposition given by $Q = \sum_n a_n P_n$, where $P_n = |v_n\rangle\langle v_n|$, and the system is in a state $\Psi = \sum c_n |v_n\rangle$ (a linear superposition of eigenstates of Q for the system), then it is possible uniquely to identify a mixed state $\mathrm{W}(Q)$ as the 'standard representative' of Q over the Hilbert space of Ψ and take it as a representation of the dispositional property possessed by Ψ that corresponds to the observable Q. $\mathrm{W}(Q)$ is equal to $\sum_n Tr(P_\Psi P_n)\, W_n$, with $W_n = \frac{P_n}{Tr(P_n)}$.

In the light of the foregoing, I therefore argue that *the fundamental components of reality are a set of colour tropes, a set of mass tropes, a set of electric charge tropes, and a set of (dispositional) spin properties,* to be defined on the basis of the empirically detected properties of elementary particles, as they are represented in the Standard Model. These properties are summarised in the table below.[13]

Particle (Antiparticle) Type (Flavour)	*Mass*[14]	*Electric Charge*	*Colour*	*Spin*
Up/Antiup Quark	1.5 to 4 MeV, probably around 3 MeV	+/–2/3	R, G or B/ AntiR, AntiG or AntiB	+/–1/2
Down/Antidown Quark	4 to 8 MeV, probably around 6 MeV	–/+1/3	R, G or B/ AntiR, AntiG or AntiB	+/–1/2
Strange/Antistrange Quark	80 to 130 MeV, probably around 100 MeV	–/+1/3	R, G or B/ AntiR, AntiG or AntiB	+/–1/2
Charm/Anticharm Quark	1150 to 1350 MeV, probably around 1300 MeV	+/–2/3	R, G or B/ AntiR, AntiG or AntiB	+/–1/2
Bottom/Antibottom Quark	4100 to 4400 MeV	–/+1/3	R, G or B/ AntiR, AntiG or AntiB	+/–1/2
Top/Antitop Quark	171400 ± 2100 MeV	+/–2/3	R, G or B/ AntiR, AntiG or AntiB	+/–1/2
Electron/Positron	0.511 MeV	–/+1	—	+/–1/2
Muon/Antimuon	105.7 MeV	–/+1	—	+/–1/2
Tau Lepton/Antitau	1777 MeV	–/+1	—	+/–1/2
Electron Neutrino/ Electron Antineutrino	<0.0000022 MeV	—	—	+/–1/2
Muon neutrino/Muon Antineutrino	<0.17 MeV	—	—	+/–1/2
Tau Neutrino/Tau Antineutrino	<5.5 MeV	—	—	+/–1/2
Photon	Energy	—	—	+/–1
W^-/W^+ Boson	0.0804 MeV	–/+1	—	+/–1
Z^0 Boson	0.0912 MeV	—	—	+/–1
Gluon	—	—	Combinations of R, G and B and AntiR, AntiG and AntiB	+/–1
Higgs Boson	>0.112 MeV	—	—	0
Graviton	—	—	—	+/–2

The elementary particles and their essential properties according to the Standard Model (Higgs bosons and gravitons are added for completeness)

13. Notice that masses are not calculated directly, but rather deduced from complex phenomena involving many particles. This is inevitable in the case of quarks, which are always confined into composites because of the fact that (due to the self-interacting nature of gluons) it would take an infinite amount of energy to split them apart.

14. The unit measure of mass is the MeV, the mega-electronvolt. An electronvolt is equal

Taking, in this fashion, the basic properties described by the Standard Model as fundamental tropes, the constitution of particles out of more elementary constituents can be readily reconstructed (and similarly for more complex entities).[15]

The way in which the tropes just identified give rise to elementary particles, I take it, is determined by the relation of mutual saturation that, as we have seen, is invoked by Denkel. As was mentioned earlier, the concept of saturation denotes the metaphysical relation of existential dependence among tropes (as determinates of specific determinables). Physical necessity legislates the way in which actual tropes (according to the view being put forward, as determinates of the determinables corresponding to the predicates 'has electric charge …', 'has mass …', 'has colour charge …' and 'has spin ...') actually get together saturating each other. That is, the way in which tropes from the existing 'resemblance families' do in fact get together in the actual world. Physical necessity also sets the constraints that tropes obey when doing so: for example, that only the particles with the smallest masses fail to be electrically charged, or that every electric charge trope needs to be saturated by a mass trope.[16]

So, for example, a trope of mass 0.511 MeV can (in fact, it must) coexist with a +1 electric charge trope and a ½ spin trope. The individual resulting from the reciprocal saturation of the charge trope, the mass trope and the spin trope in question is a positron. The same applies *mutatis mutandis* for the other elementary particles.

Structures of progressively more complex particulars can then be constituted. For instance, let an appropriate mass trope, a +2/3 electric charge

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to the amount of kinetic energy gained by a single unbound electron when it passes through an electrostatic potential difference of one volt in vacuum. In other words, it is equal to one volt times the charge of a single electron.

15. To this purpose, one might find it congenial to employ a formal framework such as, for example, the sheaf-theoretic one suggested in Mormann (1995), or the algebraic one put forward by Fuhrmann (1991).

16. An anonymous referee has objected that this may be regarded as insufficient. For, if saturation is a relation between determinables, what explains the fact that in some cases two fundamental determinables mutually saturate each other while in other cases three or four (and in still others—gravitons—a determinable might be, so to speak, 'self-saturating')? The point is, however, that the saturation relation holds among specific tropes as determinates, not among determinables. Denkel's modification of Simons' proposal only amounts to 'relaxing' the relation of existential dependence so that each trope *x* (if it needs saturation at all) depends not specifically on trope *y*, but on *y* as a member of a larger family. This makes room for replacement of *y* with a trope similar one, but does not imply that *x* must necessarily be saturated in the

trope, a ½ spin trope and a 'red' colour trope compose an up quark *a*; and similarly (of course, with different tropes) for two down quarks *b* and *c*. Individuals *a*, *b* and *c* will be among the fundamental elements at the next level of entity constitution.[17] They will determine, in particular, the formation of a neutron. The neutron will be colour-less and electrically neutral, and will have a mass which is the result of the sum of the masses of the composing quarks (increased by the energy involved in the bond among the latter). The tropes, however, remain *the same*, i.e., those of the original quarks.[18]

The same goes for each level of higher complexity: families of electrons, protons and neutrons constructed out of the basic tropes constitute atoms of the elements known in reality. For instance, 79 electrons, 79 protons and 118 neutrons give rise to an atom of stable gold. And many such atoms determine molecules and bigger pieces of gold. The 'new' properties of these latter complexes, such as 'melts at a temperature of 1064.18 C', or 'is a good conductor of heat' are—it is important to emphasise—not tropes but rather 'derivative' properties determined by the *specific* way in which the basic tropes get *structured together*.

At this point, it is worth describing substantial change in terms of tropes. I will do so at the basic level of entity constitution, that of elementary particles. It is possible, for instance, for a neutron to decay into a proton plus an electron and an electron antineutrino. This transformation can be described as one of the down quarks in the neutron having its (essential) electric charge –1/3 trope replaced by one –2/3 trope, and its (equally essential) mass trope of 6 MeV replaced by a mass trope of 3 MeV, and so become an up quark. This clearly agrees with the idea that an entity can lose one of its essential tropes and yet remain the *same* bundle (upon replacement of the trope in question with one that acts as determinate for the same determinable). The details can be accounted for—as suggested above—in terms of physical necessity: for example, one can say that such

same way as all the other tropes similar to it. It is true, on the other hand, that this view hints at internal subdivisions in the four fundamental families of tropes on the basis of the number and types of tropes required for saturation. In any event, this only concerns the details of the proposal being put forward.

17. I use 'entity constitution' to indicate the process through which tropes give rise to concrete particulars, or—at any rate—the composition of more complex complete entities out of more basic ones.

18. It is not essential here to decide whether the spin of the neutron is a new trope or just a ½ spin trope constituted by the quarks' three tropes together. I think the understanding of spin as a dispositional property leaves room for both views.

replacement of electric charge tropes 'requires'—given the laws of physics holding in this world—the production of a particle with electric charge equal to the difference between the initial and final charges, and of a neutral antiparticle. Indeed, neutron decays of the sort described (called neutron β–decays) have an electron and an electron antineutrino as by-products. Also, the masses of these can then be connected to the difference in mass between the initial neutron and the final proton (in particular, between the down and up quark) and changes in internal bonds.[19] The way in which this account of change carries over to levels of greater complexity is easy to see.

It is easy to see, generally, that the same 'dynamics' of entity constitution and change can be invoked for every progressively more complex trope-structure, and that a limited (and well-specified) set of basic tropes can therefore be conceived of as giving rise to the entire complex structure of the physical world, in terms of both particulars and their (basic and derivative) properties.[20]

The foregoing suggestion, it seems to me, fully vindicates the claim that tropes are independent, simple entities that can be considered as the basic constituents of reality, and conceived of on the basis of a simple, economic and consistent ontological framework.

This, among other things, allows one to deal with the abovementioned boundary problem: what appears to be a partition of an instance of a property into two or more other instances of the same property is just a division internal to a complex structure of tropes, the possibility of which there is no reason for denying. The division, though, necessarily terminates when one gets to the simplest components, i.e., tropes, which are in fact not divisible if identified with the properties just described. In other words, no boundary problem arises for the truly fundamental constituents of reality; whereas for the entities that are derivative on them the problem is not, in fact, a problem at all.

Looking back to Simons' proposal, it is obvious that the degree of detail provided here integrates it in the needed way, so allowing for a clearer and more plausible implementation of tropes in practice. In connection to this, two brief comments are in order. First, it can be seen that at no point is one compelled to deny that the basic tropes lack well-defined identity conditions. In particular, indistinguishable bosons can be regarded as full-blown individuals in virtue of the fact that their state-independent properties are

19. In addition, it can be specified that the process is mediated by a W^- boson.

20. This sentence must be read under the proviso that there remain open questions about reductionism and emergence. These will be dealt with (if briefly) in the next section.

(despite their exact resemblance) numerically distinct entities; and it is by no means necessary, or even advisable, to claim—as, we have seen, Simons tentatively suggests—that they give rise to new, unitary 'trope packages' when they 'get into proximity'. Secondly, the fact that quantum properties are described in terms of probabilities (which, as we have also noted, is something that puzzles Simons) is not problematic anymore once one allows for dispositional tropes.[21]

4. *State-dependent properties, emergence and entangled states*

At this point, it is time explicitly to acknowledge that one's specific view on quantum properties is inevitably affected by one's interpretation of the theory, or even by the theory, other than the so-called 'orthodox' quantum mechanics, that one adopts. For instance, within the framework of the so-called 'minimal' version of Bohmian mechanics[22], particles *only* possess 'fully state-independent' properties, and even spin is regarded as a mathematical feature of the wavefunction. Moreover, in Bohmian mechanics position has a privileged status, in that it determines the outcomes of all measurements regarding particles, and it is always unique and well-defined for each particle. It follows that probabilities only express our ignorance about the exact positions of particles, and this also applies to those probability values involved in the description of superposition states. Also, even though minimal Bohmian mechanics represents wavefunctions as sometimes superimposed, this is not a description of actual matters of fact but only of the available knowledge regarding particle positions.[23]

If, on the other hand, one restricts oneself to orthodox quantum mechanics—which was indeed tacitly taken for granted so far—it is necessary to add some more considerations to what was said in the previous sections.

21. One remaining open question is whether the different sets of exactly resembling tropes individuated earlier are reducible to 'unit-tropes', that is, whether there really is just one trope-type for each family, so that, for instance, a 4 MeV trope is in fact a composite entity constituted by four identical 1 MeV tropes. First of all, however, this possibility is not crucial to the present discussion, as the modifications that would have to be made to the account being formulated are simple and do not affect its basic structure. Secondly, as things stand presently there is no hint as to the internal complexity of the basic properties of elementary particles as these are described by the Standard Model.

22. The minimal versions of Bohmian mechanics deflate the ontological import of the wavefunctions. Some authors contend that in Bohmian mechanics these are not real but just parameters of physical laws (see Dürr, Goldstein and Zanghí (1997)).

As is well-known, quantum mechanics allows for the possibility of many-particle systems in which the component entities do not have well-defined values for a given property separately, and are instead *entangled*. Entanglement consists of a system having an overall value for a given observable while being such that its parts—although mutually correlated with respect to the measurement outcomes concerning that observable—will come to have separate values only upon measurement. How is this to be accounted for in trope-theoretic terms?

The just mentioned *non-factorisability* of entangled states into simpler states of the components, it is commonly agreed, points to some form of *holism*, namely, to the fact that certain properties of the system cannot be analysed exclusively in terms of properties of its component parts. *Property holism* (the view according to which some properties of the whole are not supervenient on properties of component parts, but sub-systems exist in spite of the non-separability of the corresponding states) would entail that these properties are emergent *relations*: the total system has an actual property plus a relation that describes what *will be* the case for the system's components without being reducible to separate monadic properties of such components.[24] A stronger form of *ontological holism* as system non-separability, determining that the system simply has no component parts before measurement, would instead require us to understand the correlation between the future separate outcomes as a *monadic property of the system* as a whole.[25]

Without the need to decide among the two options, it looks as though the properties of entangled systems can, and must, be seen as emergent tropes. In the context of ontological holism, these would be monadic in the same way as the essential state-independent properties discussed earlier. What about property holism and the talk of emergent relations? As a matter of fact, trope theory can perfectly accommodate the intuition that certain tropes are both emergent and *irreducibly relational*.

It follows that whatever interpretation one favours of the holism suggested by entangled systems, it can be captured in trope-theoretic terms.

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23. The problem arises, on the other hand, of describing the ontological nature of the 'pilot waves' in non-minimal Bohmian theories: can each guiding field be seen as a collection of tropes? Or, perhaps, as a partless whole *à la* Campbell? At any rate, there is no need to get into details regarding these matters here.

24. See Teller's (1989) 'relational holism'.

25. To my knowledge, the most recent arguments in favour of ontological holism are provided by Lange (2002).

Of course, this requires the denial of *reductionism*, both in the sense of reduction of relations to monadic properties, and of properties exhibited at a higher level of entity constitution to 'truly basic' tropes. But this, far from being a problem for trope theory, in fact appears to enlarge its possibilities and explanatory power. Generalizing, it doesn't even appear to be the case that the present proposal must be read as suggesting physicalist reductionism. As it happens for entangled states, so it could be the case for trope structures of higher complexity that, at a given level of entity constitution, not describable in the terms of physical theory, a new trope (or family of tropes) emerges that is not reducible to the more basic ones described by physics. Trope theory by no means needs to discard this possibility, and is in fact perfectly compatible with this stronger claim of property-emergence.

Before concluding, one last remark is in order. In the course of the paper, I have talked about particles and the standard model of elementary particles; and referred to quantum mechanics. Notice, however, that the Standard Model, the best model of the basic constituents of physical reality that we have available nowadays, is by no means a direct expression of any specific theory (say, of quantum mechanics as a theory of particles rather than of quantum field theory); nor, at least if interpreted in terms of tropes as in this paper, does it force upon us a particle-based interpretation of reality. Consequently, despite the specific things said, and examples given, no commitment other than to the claim that the basic 'building blocks' of reality are tropes must be read as necessary for the ontological view proposed in the present paper. Among other things, this offers the potential to put one's trope ontological views in the perspective of something more than the non-relativistic quantum mechanics considered here. Work in this direction is surely to be done, and must obviously postponed for another occasion.

5. *Conclusions*

Trope ontology has recently become a strong contender for the position of most economic, simple and empirically plausible ontology. Nonetheless, it is necessary (at least if one wants to embark in a sort of scientifically-informed metaphysics which does not remain at the abstract level of purely conceptual speculation) to check how exactly it 'fits' with what we know about reality. In this paper, Campbell's and Von Wachter's suggestion that we should endorse a field-trope ontology has been discarded, essentially on the basis of the fact that the complexity of fields seems incompatible with the simplicity that appears to be a necessary feature of fundamental tropes; and Simons' proposal based on particles has been taken to be preferable. Simons' views have been improved upon by looking at the Standard Model of elementary particles, eventually getting to a detailed explanation of what the fundamental tropes making up our world are, and how they do so. For sure, more needs to be said about tropes with respect to the entire complex array of physical theories available nowadays, and difficulties other than those considered in this paper could arise for trope theory upon philosophical analysis. At any rate, what has been proposed here is, hopefully, a useful step towards (or at least an example of) the fruitful application of the abstract schemes of ontology to the actual world.

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