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ZERO-VALUE PHYSICAL QUANTITIES*

ABSTRACT. To state an important fact about the photon, physicists use such expressions as (1) "the photon has zero (null, vanishing) mass" and (2) "the photon is (a) massless (particle)" interchangeably. Both (1) and (2) express the fact that the photon has no non-zero mass. However, statements (1) and (2) disagree about a further fact: (1) attributes to the photon the property of zero-masshood whereas (2) denies that the photon has any mass at all. But is there really a difference between saying that something has zero mass (charge, spin, etc.) and saying that it has no mass (charge, spin, etc.)? Does the distinction cut any physical or philosophical ice? I argue that the answer to these questions is yes. Put briefly, the claim of this paper is that some zero-value physical quantities are not mere "privations", "absences" or "holes in being". They are respectable properties in the same sense in which their non-zero partners are. This, I will show, has implications for the debate between two rival views of the nature of property, dispositionalism and categoricalism.

1. INTRODUCTION

To state an important fact about the photon, physicists use such expressions as

(1a) the photon has zero (null, vanishing) mass;

(1b) the photon's mass is zero

and

(2a) the photon is (a) massless (particle);

(2b) the photon has no mass

interchangeably. Do they gloss over an interesting distinction? Both (1) and (2) express the fact that the photon has no non-zero mass. However, statements (1) and (2) disagree about a further fact: (1a) and (1b) attribute to the photon the property of zero-masshood whereas (2a) and (2b) deny that the photon has any mass at all. But is there really a difference between saying that something has zero mass (charge, spin, etc.) and saying that

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it has no mass (charge, spin, etc.)? Does the distinction cut any physical or philosophical ice? Are there really such properties as *having zero mass*, *having zero spin* and the like and are they importantly different from complete masslessness, spinlessness and so on? I argue that the answer to these questions is yes. There is extensive evidence, part of which I present in the paper, in favor of the real existence of zero-valued physical quantities and their exemplification in the microphysical world. I show that such exemplification constitutes a state of affairs different in kind from mere failure to exemplify any non-zero value of the quantity in question.

Put briefly, the claim of this paper is that some zero-value physical quantities are not mere "privations", "absences" or "holes in being". They are respectable properties in the same sense in which their non-zero partners are. This, I will show, has implications for the debate between two rival views of the nature of property, categoricalism and dispositionalism.

Certainty cannot be achieved and is not sought for in a metaphysical enterprise. Consequently, none of the arguments offered below, and no conjunction thereof, establish the existence of zero-value quantities with certainty. But if these arguments can provide good reasons to believe that some such quantities exist in the full-blooded sense as suggested above, this is, I submit, a significant result. One is not naturally inclined to believe (unless one is a Hegelian) that what looks very much like nothing is really something.

2. PHYSICAL QUANTITIES: DETERMINABLES AND DETERMINATES

To get started we need some preliminaries and qualifications. First of all, we need to recall the distinction between *determinate* and *determinable* properties. Physical quantities, or *magnitudes*, form a paradigm kind of property for which this distinction is crucial. As an example, *having mass 2 kg* and *having mass 5 kg* are determinate properties of massive objects. *Having mass*, on the other hand, is a determinable property. The status of determinables and their relationship to corresponding determinates are matters of debate. One issue that has arisen in recent discussions is: *Whose* properties are determinables, such as *mass*? According to the position first set out by Johnson ((1921) 1964, Ch. 11), determinables and determinates are both properties of objects. *Having mass*, for example, is a common determinable property of massive things, which they possess in virtue of having their respective determinate masses, say, 2 kg and 5 kg. A theory recently developed by Bigelow and Pargetter (1988; 1990, Ch. 2), on the contrary, takes determinables to be (second-order) properties, not of individuals, but of their corresponding determinates.

Thus, *being a mass* is a second-order property possessed by determinate masses 2 kg and 5 kg, which, in turn, are distinct first-order properties possessed by individual objects. It is still true to say of such objects that they share a certain common property, namely "having one of the properties which is a mass". But this property is not the same as the determinable property *being a mass* shared by determinate masses. Another disputed topic is whether determinables are universals and, if not, how they manage to ground the relevant similarity, or resemblance, among individuals having corresponding determinates (or, alternatively, among determinates themselves).

Important as these issues are, we need to set them aside here. To keep the discussion maximally neutral, let us express the relationship between determinables and determinates, such as masses, by saying that an object having a particular mass, say 2 kg, *falls under* determinable *mass* or, simply, is massive. Different theories will surely put different glosses on "falls under". On Johnson's position, "falls under" will mean, in this context, "has the determinable *mass*", whereas Bigelow and Pargetter's theory will construe it as "has one of the properties which is a mass". There will obviously be other questions to raise, for example, whether *mass* is a (genuine) universal. But on virtually any theory, it is true to say of the electron that it *falls under* (whatever this could mean) such determinables as *mass*, *electric charge*, and *spin* (whether these are universals or not). Now the only sort of question we shall be concerned with is whether the photon, say, falls *in the same way* under *mass* and *charge* or, less formally, whether it has (zero) mass and charge or no mass and charge. Put another way, the question is whether, for example, a frequently used physical expression '$m_\gamma = 0$' implies the ascription of a real property (namely, zero-masshood) to the photon – just as 'm_e = 0.5 MeV' implies ascribing a particular non-zero mass to the electron – or, rather, it implies the denial that the photon has any mass property.

Physical quantities that can take zero values (or vanish – at this point we don't know which is the right way of speaking) are many and diverse. Apart from the already mentioned mass, spin, and charge, they include, for example, length, distance, duration, interval, velocity, acceleration, curvature of space, force, field strength, energy, density, pressure, temperature, as well as various chargelike properties of elementary particles: baryon and lepton charges, quark flavors, such as strangeness and charm, and color. Far from all of these are equally important in deciding the question posed in this essay: Are zero-value quantities real properties of their possessors? Many of the properties listed above are, in fact, disguised or even explicit relations, and some are derivative from more simple properties. It is trivial that the velocity of any object is zero in some reference frame (namely, in its rest frame) and that this zero velocity is a real relational quantity. It is equally trivial that the relativistic interval between two null-separated events (i.e., those belonging to the path of a light ray) is zero. This fact can hardly have deep metaphysical implications, because the interval is a derivative quantity which was *defined* in such a way as to allow negative and positive, as well as zero, values. Although the spectrum of these values reflects an important physical fact about the world (namely, the existence of the limiting velocity of propagation of causal influences), the *notion* of interval and the set of values it can take emerge from geometrical considerations. Their connection with physical reality is, to a large extent, a matter of definition and convention. This is even more so with the notion of curvature. Zero curvature generally represents flat space, but the physical significance is possessed by the underlying components of the metric, $g_{\mu\nu}$ (which are, at the same time, the components of the gravitational field), and not all of these are zero even when space is everywhere fiat. Some components of the electromagnetic field clearly can take zero values at certain points, but the import of this fact should not be exaggerated. Any chosen component of such a field can be made zero at will by going to an appropriate coordinate system, and any zero component can be made non-zero in the same fashion. The only substantive way in which a tensor quantity can be said to take a zero "value" is by having all its components equal to zero. In the case of electromagnetic field, however, this would mean the absence of the field itself, not the presence of a zero-valued field. Consider now force. There is a clear but unenlightening sense in which a *net* force acting on a body at rest is zero. An interesting question might be whether a body could ever *exert* a zero force on another body. However it might be, the notion of force understood in this manner is irrelevant, because force in the old dynamical sense is no longer part of the scientific image. Finally, it is not very illuminating to ask whether an ordinary electrically neutral macroobject – a chair, let's say, or any other sufficiently complex object – has zero electric charge or no charge. It certainly does have zero charge, but only in virtue of having non-zero charged proper parts and in a sense very different from an interesting one in which the neutrino, or even the neutron, might have zero charge (rather than having no charge at all, as the case might be).

The point of the above qualifications is to restrict the discussion to a privileged set of physical properties about which a substantive question of the existence of their zero-value determinates can be posed, which implies no trivial answer. This privileged set includes at least some of those relatively few intrinsic properties that are thought to determine the nature of the objects of the microphysical world.[1] Evidently, we have no pre-theoretical intuitions about the status of zero values of microphysical quantities.[2] Two massive particles annihilate producing a pair of photons. Does the initial mass of the particles completely disappear from the scene as a distinctive physical property (that is, totally convert into the kinetic energy of the products) or does it partly "transform" into the zero mass of the photons? Three colored quarks combine to make up a colorless proton. What does its "colorlessness" mean, the lack of color or the presence of "zero-value" color? I do not think that, offhand, we know the answer to such questions. If anything can ever commit one to the existence of a zero-value quantity, it must be its role in the causal economy of the world, and the only way to get a grip on it is to resort to the best available scientific theory. The answers such an empirical approach can deliver will, of necessity, be only provisional, but these will be the only sort of answer one can hope for.

3. THE EMPIRICAL CONCEPTION OF PROPERTY

It is important to realize that the decision to proceed empirically restricts the scope of the metaphysical implications of the analysis. According to one respectable type of theory, properties are characterized not by their causal, but by their semantic role.[3] On this view, the chief and sometimes the sole function of a property is to provide a semantic value for a predicate expression. Consequently, every predicate can be expected to deliver a real property quite irrespective of any empirical considerations. Within such a framework, it is quite natural to identify properties with sets or functions from worlds to sets in a fashion that is by now well familiar. This account easily accommodates negative and disjunctive, as well as conjunctive, properties. When properties are construed this way, it is indeed hard to see how an empirical investigation could have any impact on the question of what properties there are and, hence, on the question whether zero-value physical quantities "really" exist. To illustrate, consider two predicates:

Q_0: "___ has zero electric charge";

O: "___ has no electric charge".

The problem of zero-value quantities arises precisely because the fact that Q_0 and O are apparently true of the same physical objects (photons, neutrinos, etc.), reflecting, as it does, certain conventions adopted in the particle physics community, does not, by itself, entail the existence or non-existence of the property *having zero charge*. If, on the contrary, every predicate is taken to express a property, the whole problem simply disappears. A friend of David Lewis's (1986, §1.5) theory of property, for example, could simply take all actual and possible objects (photons, neutrinos, etc.) of which it is true to say that it is not the case that they have any non-zero charge. The set of such objects will be a property equally well expressed, in Physicalese, by Q_0 and O and there will be no further question whether this property "really" exists (of course, it does, as being a set, and any set whatsoever exists) and, if so, what it "really" is: *having zero charge* or *having no charge*. The reason is that the theory at hand recognizes no intermediate entity (e.g., universal, sense or concept) between predicate and set. For the same reason, the theory will not recognize the question, Do the objects of which Q_0 and O are true *fall under* the (determinable) property expressed by predicate Q: "___ has an electric charge"?, as an empirical question. It will be answered one way or the other, depending on whether the set expressed by Q is a superset of that expressed by Q_0 and O, and this, in turn, depends on whether the former is *taken* to include the members of the latter. There will be no further question whether the set expressed by Q *really* includes photons, neutrinos, and so on.[4]

For such a question to arise, properties must be recognized to be more than just sets. A venerable tradition draws a close connection between (and sometimes even identifies) property, on the one hand, and *meaning*, *sense* or *concept*, on the other. Thus, property is often required to provide not only an extension, but also a meaning for a predicate expression. Alternatively, such an expression can be said to express a concept, where the grasp of the latter, in turn, fixes the reference, or extension, of the predicate. Based on such a view, a bit more can be said about whether "___ has an electric charge" is true of such objects as neutrinos and photons. It is true of them if and only if the concept expressed by "___ has an electric charge" is *satisfied* by photons and neutrinos. To determine if it is, one can now rely on the "grasp" of that concept, as well as of those expressed by "___ has zero charge" and "___ has no charge". But clearly, one has not advanced too far, since the whole problem seems to be exactly about the content of these two concepts. As indicated above, we do not have any intuitive, pre-theoretical grasp of the distinction between them to the extent required to determine the extension of the corresponding predicates. Any grasp we could have must originate in what the best scientific theory tells us about the physical traits of objects that are appropriate candidates to satisfy the concepts in question.

A metaphysical view of property that thus submits to the authority of science has become known as the *empirical conception of property*.[5] It is the view to which the present analysis is geared. No empirical investigation can be required to have implications for an all-permissive theory that recognizes a property behind each and every predicate. Such implications may, on the other hand, be welcomed by a broad conception of property referred to above as empirical. For my purposes, I take this conception to incorporate the following theses:

(a) property is something more (or other) than set;
(b) the question of what properties there are cannot be decided *a priori* or based on semantic considerations;
(c) current scientific theory gives us our best guesses as to what properties there are;
(d) whereas there may be conjunctive properties, there are no negative or disjunctive ones.

Although I believe that the empirical conception of property epitomized in (a)–(d) is *the* right theory of property, I will not argue this thesis here.[6] The above explains why (a)–(c), endorsed by all who subscribe to this theory, are essential to the issue of zero-value quantities. Condition (d) is more controversial and is not universally shared by those who are otherwise sympathetic to the empirical conception of property. In assuming (d), I am siding with Armstrong (1978, Ch. 14; 1997, §3.41) and Ellis (1996, 15) and direct the reader to these authors for arguments against negative and disjunctive properties. It is important to see, however, that (d) is no less necessary than (a)–(c) to prevent the trivialization of the present issue. If $\{P_i\}$ is the set of possible non-zero values of a (discrete) physical quantity P, the omission of (d) will sanction constructing a zero-value property P_0 by taking the disjunction of $\{P_i\}$ and then negating it:

$$P_0 = \sim \bigvee_{i \neq 0} P_i .$$

While such a construction may be an interesting formal procedure, it obviates the question of whether P_0 really exists by trivializing it.

The central idea of the empirical approach to properties is that their possession must make a difference in the physical world. It must be reflected in the behavior of entities instantiating properties. In particular, the instantiation of a common property can be expected to give rise to a common physical trait, and similarity or dissimilarity in property must likewise be adequately reflected in physical behavior. Such considerations will form the basis of my defense of the existence of zero-value quantities.

It is worth emphasizing that the empirical conception of property as outlined in (a)–(d) is sufficiently general to leave many important questions about the nature of property open. Among the adherents of this broad conception we find both universals- and trope-theorists, “dispositionalists” as well as “categoricalists”, essentialists and their rivals, the friends of natural kinds and their enemies. Although it is not my intention in this essay to examine these particular views in detail, I will attempt, in the end, to draw some lessons from the following analysis for the debate between dispositionalism and categoricalism.

It is finally time to see how the existence of zero-value quantities can make a difference.

4. FOUR ARGUMENTS

The rest of the paper is essentially an interplay of the four types of argument. Before embarking on the specifics, I wish to sketch the general structure of these arguments.

1. *Argument from Composition.* Suppose particle a is a bound state (roughly, a physically allowed and, in principle, detectable compound) of two particles b^+ and b^- having non-zero (determinate) quantities P_b^+ and P_b^- summing up to 0. I suggest that it is more reasonable to say that a has zero value of P, $P_a = 0$, than to insist that it has no P at all. P-hood cannot simply disappear when combined with another P-hood in a productive way.

   The argument is easily generalized to apply to bound states of more than two components. To put it informally, two or more P-hoods cannot result in complete P-lessness.
2. *Argument from Parity*. When particle a is a $P = 0$ bound state of b^+ and b^- (as above), or of more particles, and particle c is a simple object claiming for itself the property $P_c = 0$, this claim is corroborated to the extent that the possession of P can be related to a relevant common trait in the physical behavior of both a and c.

   The force of this argument is proportional to the force of ‘relevant’. This can be increased by showing that the same *kind* of generic trait in behavior is related to a *non-zero* value of P in other objects.
3. *Argument from Unification.* If particle c claiming for itself $P_c = 0$ and particle d with $P_d \neq 0$ exhibit a generic physical trait that is related to P-hood, this supports the claim that c has $P_c = 0$ (rather than no P at all).

   The idea here is that it would be unnatural to suppose that d behaved in a certain P-dependent way thanks to having P and c behaved in the same way thanks to lacking P.

Now, suppose a joint employment of Arguments from Composition, Parity, and Unification favors the existence of a certain zero-P-hood. This claim could then be thrown into still sharper relief by showing that zero-P-hood is interestingly different from P-lessness – that entities conjectured to have $P = 0$ display, thanks to this property, a trait that is absent in the behavior of entities presumed to have no P at all, and vice versa.

4. *Argument from Disparity*. If c claims $P_c = 0$ and e is unlikely to have anything to do with P-hood and these types of particle differ in a physical trait known to relate to P-hood and its absence, this strongly supports the claim that c really has $P_c = 0$.

The above argument schemes bear a close resemblance to the general principles of empirical inquiry, as expounded, for example, in Bacon's Tables and Mill's Methods. Speaking in the manner of Bacon, what we are looking for is the "nature", or "form", of a class of phenomena characterized either by a zero value of a certain quantity P or, alternatively, by the complete lack of P. We want to determine which of these options is the correct one. The joint application of the four Arguments amounts, in effect, to, first, assembling known instances of P and finding, among them, putative instances of $P = 0$ and, then, ideally, to opposing such instances to those in which P is absent. Along the way, we widely use various "prerogative instances": "solitary instances" (when two objects, otherwise the same, differ with respect to only one characteristic), "analogous instances" (when one phenomenon throws light on another), and "crucial instances" (decisive ones, when the mind is at the crossroads or divided between two equally compelling options).[7]

Now to arguments themselves.

5. SPIN

5.1.

Various pairs of quark and anti-quark, each having the absolute value of spin 1/2 (expressed in units of $\hbar = h/2\pi$), combine to produce particles known as mesons. These generally have integral value of spin and often occur in spin-zero states known as pseudo-scalar mesons.[8] Should one take this literally and ascribe to such mesons property $S = 0$ or no spin property at all? By the Argument from Composition, it is, in all likelihood, the former rather than the latter: spinness plus spinness can hardly result in complete spinlessness.

5.2.

Even so, one may not be persuaded by the case of the mesons alone. These are, after all, composite states of more fundamental particles having non-zero spin. What if the only properties that really exist in this situation are non-zero spins of the quarks which "cancel out" to yield zero net spin of a pseudo-scalar meson? In other words, what if zero net spin of this composite particle is not ontologically basic in the sense that it could be completely reduced to the underlying properties of the constituents? To dispel this worry, notice, first, that bound states in particle physics behave, in many ways, as structureless entities. True, they do have structure and it does manifest itself in certain effects.[9] But it is an important fact about bound states in general, and quark bound states in particular, that many of their properties, while not being ontologically basic, are attributable to them in the *same* physical sense in which truly basic and irreducible properties are attributed to their elementary constituents.

Spin is actually a good example of such a property. Consider, again, a pseudo-scalar $S = 0$ meson, such as the π^+. It is made up of an u quark and a $\bar{d}$ anti-quark (see Table 1). The spin of the π^+, S_{π^+}, is none other than the total angular momentum $J_{J_{u\bar{d}}}$ of the composite $udJ_{u\bar{d}}$ includes the spins of the $u(S_u = \frac{1}{2})$ and the $\bar{d}(S_{\bar{d}} = \frac{1}{2})$, as well as the orbital momentum of the bound state $u\bar{d}$, $L_{w\bar{d}}$, which can take zero or any positive integer value, $L_{u\bar{d}} = 0, 1, 2, \ldots$. The numbers S_u, $S_{\bar{d}}$, and $L_{u\bar{d}}$, however, do not, in general, simply "add" to yield $J_{u\bar{d}}$. Rather, S_u, $S_{\bar{d}}$, $L_{u\bar{d}}$, and $J_{u\bar{d}}$ obey more complex relations known as angular momenta addition rules, which we need not go into. We only need to note here that the π^+ is an $L = 0$ bound state of the u and $\bar{d}$, for which $S_{\pi^+} = J_{u\bar{d}} = S_u - S_{\bar{d}} + L_{u\bar{d}} = 0$. Interestingly, the same quark-anti-quark pair $u\bar{d}$ can form another $L = 0$ bound state, the *vector* meson ρ^+, with $S_{\rho^+} = J_{u\bar{d}} = S_u + S_{\bar{d}} + L_{u\bar{d}} = 1$. Now the important fact about the ρ^+ is that it behaves, in all spin-related phenomena, like a truly elementary spin-1 particle. In the same vein, the π^+ behaves, in all such phenomena, as a truly elementary spin-0 particle would do. There is, in general, no spin-related trait that would distinguish a spin-*n* bound state from a spin-*n* fundamental object. Hence, there is every reason to take the spins of bound states seriously. Furthermore, spin-1 and spin-0 states should be taken *equally* seriously.

All said, it would be nice, in addition to a spin-0 composite, such as the π^+, to have at hand an example of a truly fundamental spin-0 particle. Such particles, known in theory as scalar bosons, have not yet been observed in experiment. But there is a very strong candidate, the so-called Higgs boson, which is a quantum of a field that plays such a crucial role in the best available (and firmly supported by experiment) theory of fundamental interactions (viz., the Standard Model) that very few high-energy physicists doubt its existence. The search for the Higgs boson is a top priority in the field.

If the Higgs boson exists, it must, by the Argument from Parity, have spin zero, rather than no spin at all. Indeed, both sorts of particle, the Higgs boson and the pseudo-scalar mesons, have precisely the same spin-related physical traits; in particular, they exhibit the same type of statistics and have both exactly one polarization state.[10] It would be odd to say that the mesons display these traits in virtue of having spin zero whereas the Higgs boson does precisely the same in virtue of having no spin at all.

The Argument from Parity makes zero-spinhood a package deal: either both the $S = 0$ mesons and the Higgs particle have zero spin or none. And in light of the Argument from Composition, it is hard to maintain the latter for the pseudo-scalar mesons. Surely they have something like a spin *structure*, as being composed of two spin-1/2 components.

5.3.

If one is still unconvinced, an Argument from Unification may help clear up lingering doubts. Spin-0 particles belong to the family of the bosons, particles with integral spin ($S = 0, 1, 2, \ldots$). What unites all bosons in a single family is that they all obey a common type of quantum statistics, the Bose–Einstein one. The wave function of many-boson systems possesses a distinctive sort of symmetry resulting in there being no restriction on the number of identical bosons that can occupy the same quantum state. That this trait is shared by spin-0 bosons with spin-1 (spin-2, …) ones is empirically perspicuous in such effects as superconductivity, where pairs of opposite-spin electrons are believed to form $S = 0$ bound states referred to as Cooper pairs.

Anyone denying that spin-0 particles really have zero-spinhood and thereby fall under determinable *spin* would have to deny that such particles belong to the family of bosons thanks to *having* integral spin. She would have to explain this membership on other grounds, and one wonders what grounds would be good for it. Most important, she would be forced to admit that, whereas obeying the Bose–Einstein statistics is a matter of having integral spin for vector bosons (with $S = 1$), it is a matter of having no spin at all for scalar bosons (putative $S = 0$ particles or bound states). A most unnatural thing to say.

5.4.

The above considerations relied on well-established physics. The following one, on the contrary appeals to a relatively recent hypothesis in particle theory and should, consequently, be taken with a certain reservation. Widely known under the name of Supersymmetry (SUSY), the hypothesis, however, is regarded by many in the business as being indispensable to further progress in high-energy physics. According to SUSY, there is a higher type of symmetry interrelating bosons (particles with integral spin) and fermions (particles with half-integral spin, such as quarks and leptons). Symmetry in particle physics always means some sort of unification. In case of SUSY, the unification is really "across the board", as it purports to relate entities – fermions and bosons – that have always been thought to represent radically different categories of "matter" and "force". One consequence of SUSY is that almost all known bosons and fermions must have supersymmetric "partners". Thus the spin-0 Higgs boson will occur in a single multiplet with spin-1/2 "Higgsino", whereas spin-1/2 quarks and leptons will have, as their partners, spin-0 "squarks" and "sleptons". Spin being the pivotal point of the SUSY unification, it would seem illogical to grant the spin property to one supersymmetric partner, such as an $S = 1/2$ lepton, and to deny it to the other, such as an $S = 0$ slepton.

6. MASS

Mass is a property that instigated my interest in zero-value quantities in the first place. Anticipating the results of this section, however, I wish to note that mass, very unlike spin, charge, and other charge-like properties, has not met my initial expectations. As I will show in a moment, the case for zero-masshood remains inconclusive. Even so, I find it useful to examine this case, if only to contrast the putative nature of zero-masshood with the real nature of other zero-value quantities whose exemplification in the world of elementary particles can be established with more certainty. Drawing attention to this contrast is methodologically important, because it illustrates that the general claim of this paper – that some zero-value quantities are full-blown properties possessed by microobjects in the same positive sense as their non-zero companions are – is neither trivially true nor trivially false, but turns in each instance on the examination of particular causal roles played by these properties.

Mass is interesting for yet another reason that is rather tangential to the concerns of this paper but important in its own right, and it certainly deserves special consideration. One of the most surprising conclusions to be drawn from the Standard Model is that mass – that is, *rest* mass – may not, after all, be an intrinsic property of things. For all we know, it may be a *relational* properly. But let us treat these matters in their natural order.

The very idea of a massless particle is nonsense in classical mechanics. Such a particle would experience infinite acceleration under any force – a clearly unphysical result. Special relativity, on the contrary, appears to allow for particles of zero (rest) mass. This possibility is incorporated into the equation relating energy, momentum and rest mass in relativistic mechanics:

$$(1) \qquad E^2 = m_0^2 c^4 + p^2 c^2.$$

For a particle with zero (or no, as the case might be) rest mass, this gives: $E = pc$.

The primary candidate for $m_0 = 0$ is the photon. The gluons, intermediate vector bosons carrying the strong color force among the quarks, are also believed to be massless, although the situation there is not so clear as with the photon. It is still less clear with the neutrinos. They have, for a long time, been thought to be massless (or of zero mass). But there is now a growing suspicion that all three known species of the neutrino might have a small mass. The neutrinos' non-zero masses would be welcomed by astrophysics and cosmology. More important, there are no general principles that disallow the neutrinos to have non-vanishing mass, and according to a tacit rule adopted in particle physics, what is not strictly forbidden must exist. There are, on the other hand, sufficiently general principles that preclude the photon from having non-zero mass. So it would be wise to focus on this particle for the present analysis.

6.1.

These mass-prohibiting principles are, by themselves, of no help in deciding whether the photon has zero mass or no mass at all. Considerations of relativistic kinematics mentioned above go some way towards this goal, but their overall impact is far from decisive. On the one hand, massless (or mass-zero) photons are treated by the relativistic Equation (1) on a par with massive objects, and this suggests that, by the Argument from Unification, both sorts of object exhibit a common trait by sharing a common determinable, namely mass. To apply Equation (1) to the photon, one actually has to put $m_\gamma = 0$ in the equation, just as one puts there $m \neq 0$ for massive objects. On the other hand, it is far from clear that this procedure should be taken too literally and can warrant far-reaching metaphysical conclusions. The mechanical behavior of the photon (and of other $m = 0$ objects, if there are any) is very peculiar, in that the photon, unlike "normal" massive objects, does not occur at rest. Isn't it at least plausible to relate this peculiarity to another one, such as the absence of mass? There is nothing unreasonable in saying that the photon exhibits its characteristic kinematic behavior due to the lack of a certain determinable property, namely mass. And the Argument from Unification, pointing, as it does, to a common relativistic trait displayed by massive and massless objects, seems, in this case, too general and amorphous to dispel – all by itself, unaided by other arguments – the doubts that might be raised by the peculiarity of the photon's kinematic behavior.

6.2.

Let us see if these doubts can be overcome at a more fundamental level. According to the Standard Model, electromagnetic and weak interactions are different manifestations of a single electroweak force described by the Weinberg–Salam–Glashow (WSG) theory.[11] This unified theory includes four gauge bosons: the photon, the $W^{\pm}$, and the Z^0, the first mediating the electromagnetic interaction and the rest the weak one. These forces manifest themselves rather differently – the electromagnetic force being, for example, long-range and the weak one short-range – because the mediator of the former, the photon, is massless (or has zero-mass, as it might be), whereas the W's and Z^0 are massive particles ($m_{W^{\pm}} \approx 82$ GeV, $m_Z \approx 93$ GeV). But both the massless/zero-mass photon and the heavy W's and Z^0 perform similar causal tasks. They are quanta of fields resulting from a general principle of local gauge invariance. Furthermore, the theory starts with four massless (or zero-mass) vector gauge fields and couples them with the scalar Higgs field (which already occurred in our discussion) in such a way as to *generate* non-zero masses of the three gauge bosons and to leave the fourth one massless (or, alternatively, to preserve its zero mass). The mechanism of mass generation (known as the Higgs mechanism) lies at the heart of the electroweak unification. Not only does the massless/zero-mass photon find itself in the company of massive $W^{\pm}$ and Z^0. The photon and the Z^0, being both electrically neutral, come out as a result of a special "mixing" of the initial, massless or mass-zero, gauge fields associated with the underlying SU(2) $\times$ U(1) symmetry. Because this symmetry is "broken" (by the Higgs mechanism), these initial neutral states "mix" to produce one $m = 0$ linear combination (the photon) and an orthogonal $m \neq 0$ combination (the Z^0).

This intricate alchemy of unification suggests that the photon has many common traits with the heavy gauge bosons. Since these traits are linked to the mass property of the electromagnetic and weak force carriers, it seems natural to back up this unification with ascribing mass to all the four bosons including the photon (whose mass is, of course, zero), rather than maintaining that three of them perform their common causal role in virtue of having mass and the fourth in virtue of lacking this (determinable) property.

Unfortunately, the WSG theory suggests much more than this. Because of its reliance on the Higgs mechanism of mass generation, it suggests that the mass of gauge bosons – and, in fact, the mass of the "matter" particles, the leptons and the quarks – may *not* be an intrinsic property of its bearers. It may indeed be a *relational* property which the regular bosonic and fermionic fields *acquire* through their special relationship to the Higgs field. If this lesson is really to be drawn from the story, it is, to be sure, a most surprising one. We tend to think of (rest) mass as a paradigm of intrinsic property and some would perhaps deplore its dissolution into a relation as a total calamity The microworld is indeed full of surprises. But I will leave it for another paper to decide if the prospect just hinted at is really as disastrous as it might appear. Here I only wish to point out that if mass is really a relational property or a disguised relation, the force of the considerations that have just been brought in favor of the existence of the zero mass of the photon will be undermined. We have seen earlier that relational quantities (such as velocity or acceleration) acquire zero values rather easily without thereby raising any substantive metaphysical quandaries. It is, in general, easy and unproblematic for a to bear a zero-value quantitative relation to b. But we are interested here in what is truly problematic, namely, the nature of *intrinsic* zero-value quantities.

I conclude that the issue of zero-masshood remains ambiguous. It may be interesting to compare it with the case of spin discussed earlier. There we had a whole battery of mutually supporting arguments favoring the existence of zero-spinhood. The entire case for zero-masshood, on the contrary, was based on an inconclusive application of the Argument from Unification and this, by itself, proved insufficient. It is easy to see what prevents one from applying to mass (even if it were, *pace* the Standard Model, an intrinsic property) other types of argument listed at the beginning of this section, such as the Arguments from Composition and from Parity. In contrast to spin and certain other fundamental properties, mass does not allow for negative values and, hence, for $m = 0$ composites of two or more $m \neq 0$ elements. Furthermore, unlike spin and charge, mass is a *continuous* quantity that is not quantized.[12]

I now turn to a family of properties that, like spin, lend more credence to the thesis of this essay.

7. CHARGE AND CHARGELIKE QUANTITIES

Chargelike properties of elementary particles include, besides electric charge, such quantities as baryon and lepton charges, quark flavors (“up”, “down”, strangeness, charm, beauty, and “top”), and color. What makes these “like charge” is that they are all quantized (i.e., come in multiples of common units) and can take negative, as well as positive, values. The question, then, is whether they can also take zero values in an interesting ontological sense.

7.1.

To begin with electric charge, recall, first, that many electrically neutral particles are bound states of non-zero charged components (Table 1). Thus the neutron is a bound state of three charged quarks, and the neutral mesons are bound states of quark-anti-quark pairs. Do these composites have zero charge or no charge? By the Argument from Composition, it is the former rather than the latter, and the whole litany must by now be familiar. The neutron, for example, has no net charge but it has a charge *structure*, which can be probed in deep inelastic scattering experiments. In such experiments, a beam of electrons is scattered off neutrons producing jets of hadrons. The scattering pattern shows that the neutron has internal structure and that incoming electrons interact with individual quarks. It appears inescapable that what has a charge structure must have something to do with the charge property. Although such an object may be electrically neutral, its neutrality is a matter of having zero net charge rather than no charge at all. Several charges taken together cannot (unless they annihilate with the production of truly chargeless objects) result in complete chargelessness, although they may result in zero total charge.

To reinforce this conclusion, apply an Argument from Parity and compare the electromagnetic behavior of the neutron with that of the neutrino, a genuinely elementary electrically neutral particle. Except for phenomena in which the internal charge structure of the neutron becomes important, the neutron and the neutrino are perfectly on a par as far as their electromagnetic traits are concerned. Neither is influenced by the electromagnetic field, for example, and neither leaves tracks in particle detectors (because of an inability to ionize detector media). Consequently, either both the neutron and the neutrino have (zero) charge or neither of them do. But we have seen that the neutron has a charge structure and that it would be strange to admit this structure and to deny to the neutron the charge property. Therefore, et cetera.

TABLE I

Quark content and some quantum numbers of baryons and mesons

Baryons				
Baryon	Quark content	Charge	Spin	Baryon number
p	uud	$+1$	1/2	$+1$
n	udd	0	1/2	$+1$
Λ	uds	0	1/2	$+1$
Σ^+	uus	$+1$	1/2	$+1$
$\Delta^{++}, \Delta^+, \Delta^0,$	$uuu, uud, udd,$	$+2, +1, 0,$	3/2	$+1$
Δ^-	ddd	-1	3/2	$+1$
…	…	…	…	…
Mesons				
Meson	Quark content	Charge	Spin	Baryon number
$\pi^\pm$	$u\bar{d}, d\bar{u}$	$+1, -1$	0	0
π^0	$(u\bar{u} - d\bar{d})/\sqrt{2}$	0	0	0
$K^\pm$	$u\bar{s}, s\bar{u}$	$+1, -1$	0	0
ϕ	$s\bar{s}$	0	1	0
J/ψ	$c\bar{c}$	0	1	0
…	…	…	…	…

The structural aspect of the neutron's zero charge may, however, raise a doubt that, despite all similarity, the ontological nature of the neutron's charge may be different from that of the neutrino's. A similar doubt regarding the spin of composite objects, such as the pseudoscalar mesons, has already been discussed and dismissed in Section 7.1. However, the issue is an important one and I would like to address it again, this time approaching it from a more philosophical angle. What if the neutrino is truly chargeless (i.e., has no charge at all), whereas the zero charge of the neutron is but a "second-rate" property supervening on non-zero charges of the constituent quarks? Supervening entities, in Armstrong's felicitous expression, are not an "addition to being" but rather an "ontological free lunch" (1997, 11–13).[13] Perhaps what we really have here are charged objects (the quarks), on the one hand, and chargeless ones (the neutrino), on the other. If there is no real property of zero-chargehood possessed by the neutron – if this property is just an "ontological free lunch" resulting from the interplay of non-zero charges of the constituent quarks – then there is, perhaps, no reason to postulate such a property as the zero charge of the neutrino. Both the neutron and the neutrino could well exhibit their common electromagnetic traits thanks to *lacking* the determinable property of charge (rather than in virtue of having zero charge), the former (i.e., the neutron) lacking it because it is a composite entity and such entities, as well as their properties, are, strictly speaking, not an "addition to being", and the neutrino lacking charge in a more basic sense.

I would like to make two points in response, one metaphysical and another more physical in character. First, the force of the objection is proportional to the degree of seriousness with which one is prepared to endorse the thesis of "ontological free lunch". Despite its obvious appeal, the thesis is controversial. Taken to the extreme, it would imply that supervening entities – for example, atoms, molecules, tables and chairs, as well as their properties – do not, strictly speaking, exist. This is surely a conclusion hard to accept. On a more moderate reading implicit in Armstrong (ibid.), atoms, molecules, and so on, together with their properties, do exist but are not an "addition to being". What exactly is being asserted here? Are there two senses of existence, or being, at play? There is, I take it, a clear sense in which it is not the case that there are elementary particles arranged in various ways and, *besides*, there are atoms, molecules, and so forth. But does it mean that there are no such entities as atoms and molecules and that their properties are non-existent? Hardly so. Armstrong suggests that one should think of the supervenience of mereological wholes on their parts in terms of *identity*: "Mereological wholes are not ontologically additional to all their parts, nor are the parts ontologically additional to the whole that they compose. This has the consequence that mereological wholes are *identical* with all their parts taken together. Symmetrical supervenience yields identity" (1997, 13). If so, then one can say that it is not the case that there is a certain molecule and, *besides*, there are atoms composing it and yet avoid the conclusion that the molecule does not exist. Rather, the molecule and the atoms composing it both exist as being one and the same. It is not clear, however, that similar reasoning applies to *properties* that can be attributed to wholes and their constituent parts. The relation between these two sets of properties is not a mereological relation. A property of the neutron, say its charge, is not just identical with a certain whole composed of the properties of the constituent quarks and gluons.

The doctrine of "ontological free lunch" certainly deserves more discussion than can be afforded here. Leaving for now his debatable topic, I wish to point out that, quite independent of the general metaphysical status of ordinary supervening entities, there are physical reasons to accord the neutron and other hadrons composed of quarks a status different from that enjoyed by more mundane composite objects. I am alluding here to a phenomenon known as *quark confinement*. Because of confinement, free quarks do not occur in nature and hadrons cannot, *in principle*, be decomposed into their constituent quarks. Loosely speaking, if you try to break the neutron into quarks, you end up creating more hadrons without, at any point in the process, confronting free quarks (Figure 1). Given this remarkable effect, it is difficult to see how one could avoid taking such entities as the neutron and its properties as existing in the most fundamental sense, even if one were inclined to treat atoms and the like as ontological free lunch.

Returning to the issue of zero charge, it is worth emphasizing that, just as with zero spin, various arguments supporting the case of zero-chargehood enhance their strength by mutual support. Having thus exploited Arguments from Composition and from Parity, I want now to tie them to an Argument from Unification. To run such an argument, one has to identify a common charge-related trait exhibited both by an electrically charged particle and by an electrically neutral one. Such traits are not difficult to find. First, we recall from an earlier discussion that the charged $W^{\pm}$ and the neutral Z^0 belong to the family of intermediate gauge bosons carrying the weak force. Furthermore, the Standard Model features three generations of leptons and quarks:

$$\left\{\begin{matrix} e^- & d \\ \nu_e & u \end{matrix}\right\}, \quad \left\{\begin{matrix} \mu^- & s \\ \nu_\mu & c \end{matrix}\right\}, \quad \left\{\begin{matrix} \tau^- & b \\ \nu_\tau & t \end{matrix}\right\}.$$

Within each generation, two leptons, such as the electron (e^-) and its neutrino (ν_e) (as well as two quarks, such as the up (u) and down (d)) stand in a most intimate relationship to one another, as being *doublets* of the SU(2) symmetry group. Consider such a weak isospin doublet of the e^- and ν_e:

$$\psi = \begin{pmatrix} \psi_{e^-} \\ \psi_{\nu_e} \end{pmatrix}.$$

"Rotations" in the weak isospin space generated by SU(2):[14]

$$\begin{pmatrix} \psi_{e^-} \\ \psi_{\nu_e} \end{pmatrix} \to e^{i\frac{1}{2}\tau_\kappa \alpha_k x} \begin{pmatrix} \psi_{e^-} \\ \psi_{\nu_e} \end{pmatrix}$$

enable the states ψ_{e^-} and ψ_{ν_e} to "mix" resulting in other allowed states. The weak force, in the form of three intermediate gauge bosons, arises, as it is sometimes said, from "neutralizing" the effect of such "rotations", in accordance with the principle of local gauge invariance. What interests

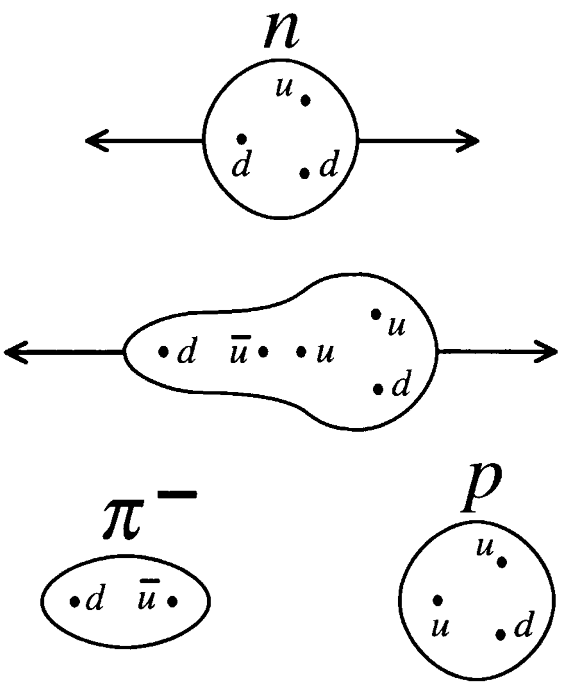

Figure 1. Quark confinement.

us most is the fact that a single SU(2) doublet contains both the charged e^- and the neutral ν_e. In order to be able to "mix" with one another properly, the e^- and ν_e clearly must possess a significant number of common properties. "Mixing" would be impeded if the neutrino lacked a relevant property possessed by the electron and vice versa. There is reason to suppose that charge is one of those credentials that the neutrino must present to be allowed into the company of the electron. Of course, the neutrino's charge is zero and the electron's is not. But what appears essential is that both particles share a common determinable property, namely *charge*.

How exactly is it essential? The matter is not a simple one and, in fact, it might be objected that electric charge is entirely irrelevant to the unification of the e^- and ν_e in a weak isospin doublet. Charge has to do with the electromagnetic force, whereas what unites the e^- and ν_e in

$$\psi = \begin{pmatrix} \psi_{e^-} \\ \psi_{\nu_e} \end{pmatrix}$$

is their participation in the *weak*, not electromagnetic, interactions. This is, indeed, how things stood before the advent of the WSG theory. With this theory, a unification of the two kinds of forces was achieved. To take

TABLE II

Weak isospin, charge, and hypercharge quantum numbers of the first family of leptons

Lepton	T_3	Q	Y
ν_e	$\frac{1}{2}$	0	-1
e_L^-	$-\frac{1}{2}$	-1	-1
e_R^-	0	-1	-2

account of the fact that parity (another fundamental physical property) is not conserved in weak interactions, WSG had to incorporate an invariant quantity called *hypercharge*, which is a certain linear combination of the usual electric charge and one of the components of isospin.

Parity violation is introduced into WSG by assigning the left- and right-handed[15] components of the fermions to different group representations. Thus, the neutrino and the left-handed electron form a doublet of SU(2),

$$\psi_L = \begin{pmatrix} \psi_{\nu_e} \\ \psi_{e_L^-} \end{pmatrix},$$

whereas the right-handed electron stands alone as a singlet, $\psi_R = \psi_{e_R^-}$, because of the absence of the right-handed neutrino. To treat both the doublet and the singlet in an invariant way, the Lagrangian of the electroweak theory must include the generator Y (the weak hypercharge), which relates to $T_3 = \frac{1}{2}\tau_3$ (the third component of isospin) and Q (the electric charge operator) as $Y = 2(Q - T_3)$. T_3 is easily linked to Q (thus producing an invariant combination, that is, Y) precisely because the members of the SU(2) doublet are eigenstates of T_3 whose engenvalues differ by a unit of electric charge (Table 2).

Thus, because of electroweak unification, electric charge becomes an essential property for placing members into SU(2) doublets, such as

$$\psi_L = \begin{pmatrix} \psi_{\nu_e} \\ \psi_{e_L^-} \end{pmatrix}.$$

Unification effectively puts the (non-zero) charge of the electron and the (zero) charge of the neutrino to work. But to be capable of being put to work, this property evidently must exist in both cases.

To sum up, the electrically neutral neutrino shares an important trait with the electron and charge is essential to this common trait. The Argument from Unification prompts one to take the neutrino's zero charge with ontological seriousness.

7.2.

Some considerations concerning the electric charge apply, *mutatis mutandis*, to other chargelike properties of elementary particles, specifically, to quark colors and flavors. I will only examine color here. As already noted, quarks and gluons (the bosons mediating the strong interaction among quarks) carry a special quantity called color. But physically possible bound states of quarks, the baryons and the mesons, possess no net color. In physical parlance, they are color*less*. But we have seen that such expressions may be misleading. Although baryons and mesons have no net color, they do have color structure. Consequently, it is more appropriate to say that they have "zero color".[16]

One can see, once again, an Argument from Composition at work here. In contrast to electric charge, however, color does not submit to the Arguments from Parity and Unification. The reason is that there are no elementary objects (not bound states of more basic particles) that have zero color. At the same time, there are many elementary objects that are strictly *colorless*, that is, devoid of any color at all. Such are, for example, the leptons, particles not participating in strong force. What is the substantial difference between zero-color hadrons – say, the proton and the neutron – and colorless electrons, neutrinos, and so on? The former strongly interact amongst themselves (for example, inside atomic nuclei) and this interaction is due to the residual color force among the constituent quarks and gluons, which "transpires" beyond the limits of the hadrons (Figure 2). The leptons, on the other hand, have nothing to do with color force.[17] This distinction is real and physically important and thereby provides a valuable material for an Argument from Disparity. As Bacon would say, the "nature" or "form" of color seems to be present in zero-colored nucleons (i.e., the neutron and the proton) and absent in colorless leptons.

Consider, finally, a very similar case of *baryon charge* or *number* (B), a quantity possessed by quarks and lacked by leptons.[18] All quarks have $B = 1/3$ and all anti-quarks $B = -1/3$. Each baryon is composed of three quarks and, thus, carries $B = 1$ (hence the name of this kind of particle). Each meson, on the other hand, is a combination of a quark and an anti-quark and, as a result, has $B = 0$. Strong interactions involving baryons and mesons, such as the decay of the unstable Δ^{++}:

$$\Delta^{++} \to p + \pi^+,$$

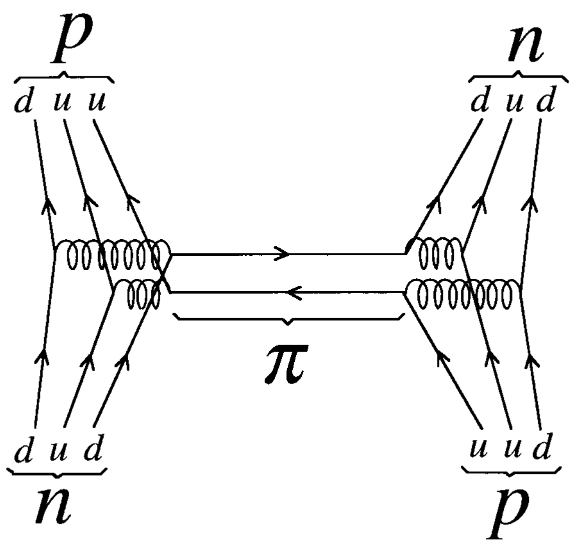

Figure 2. Strong interaction of protons and neutrons inside atomic nuclei. Individual quarks (solid lines) strongly interact by the exchange of gluons (spiral lines). This interaction "transpires" beyond the limits of protons and neutrons thus binding them together in a nucleus. The process can be usefully looked upon as the interaction of whole nucleons (i.e., the neutron and the proton) by the pion exchange.

conserve the baryon number. Here $B_{\Delta^{++}} = B_p = +1$, $B_{\pi^+} = 0$. Now it is customary to assign $B = 0$ to the leptons as well, since these interact (electromagnetically and weakly) with the hadrons and all such reactions proceed (according to the Standard Model – but see below) with the conservation of the baryon number, as in the following example:

$$\Sigma^- \to n + e^- + \bar{\nu}_e.$$

Here $B_{\Sigma^-} = B_n = +1$, $B_{e^-} = B_{\bar{\nu}_e} = 0$.

But we have learned enough not to take such expressions at face value. In particular, we are prompted to apply an Argument from Disparity to a distinction that cuts physical ice, and the distinction between $B_{\pi^+} = 0$ and $B_{e^-} = 0$ certainly does. The π^+ has zero baryon charge because it has a "balanced" baryon structure (see Table 1). The electron, on the contrary, has neither such a structure nor any traits that can be associated with baryon-chargehood and, hence, no baryon charge at all.

This said, let us note that the situation is likely to change if one goes beyond the Standard Model. The first step in this direction would be a successful Grand Unified Theory (GUT). If such a theory proves adequate, it will blend together electroweak and strong forces. One probable consequence of such a unification will be the overthrow of the baryon number conservation in reactions such as the proverbial proton decay:

$$p \to e^+ + \pi^0.$$

Such a process would be made possible by a new type of overarching symmetry presumed to hold among the leptons and the quarks. For example, the simplest (and by now considered empirically refuted, as predicting too short a lifetime for the proton) GUT based on the group SU(5) brings with it a unification of three right-handed components of the three colors of the down quark, d, the positron e^+_R, and the antineutrino $\bar{\nu}_e$ in a single 5-plet: (d^{red}_R, d^{green}_R, d^{blue}_R, e^+_R, $\bar{\nu}_e$). This schema, as we shall see in a moment, legitimizes assigning zero baryon charge (and also "zero color") to the leptons and zero lepton number to the quarks. Disparity referred to above between zero-baryon-charged mesons and baryon-chargeless leptons disappears and, with it, the springboard for an Argument from Disparity. But at the same time, a possibility immediately opens for the Arguments from Parity and Unification to take over. The situation becomes exactly parallel to the case of the electric charge considered earlier in the context of electroweak unification operating on SU(2) doublets of leptons. Just as the combination of the neutrino with the electron in such a doublet suggests that the former has zero charge (rather than no charge), combining e^+_R and $\bar{\nu}_e$ with the quarks in a SU(5) 5-plet suggests the zero baryon charge of the leptons. $B_{e^-} = 0$ now has to be taken seriously.

To sum up the discussion of the baryon charge, we have something of a case argument here. Within the Standard Model, baryon number is conserved, electroweak and strong forces stand separately, and, as a consequence, an important distinction obtains between the mesons whose baryon charge is zero and the leptons which do not have this property at all. This difference is reason enough to believe in the reality of $B = 0$, since zero-baryon-chargehood imparts to its possessors traits that are absent in baryon-chargeless objects. If one transgresses the limits of the Standard Model, it is no longer correct to deny (zero) baryon charge to the leptons, as they now find themselves in the same boat with the quarks. This, again, strongly suggests the reality of $B = 0$, but for a different reason. Either way, zero-baryon-number-hood is exemplified in some entities or others.

8. DISCUSSION. NEW WORK FOR CATEGORICALISM

If the arguments of Sections 5–7 achieve their goal, they provide ground for believing in the existence of at least some zero-value physical quantities. It is important to situate this belief where it truly belongs, in the framework of the empirical conception of property presupposed throughout the present analysis. If select zero-value quantities really exist, they do so in a manner and for reasons very different from those which a permissive metaphysical theory typically alludes to when it grants existence to such properties as *being colored if red* or *being such that 7 + 5 = 12*. On the empirical conception of property, it is not the case that every predicate satisfied by some individual expresses a property. Existence of properties cannot be distilled from semantics. What properties there are is an open question which cannot be decided *a priori* but requires empirical investigation guided, in each particular case, by the best available scientific theory.

The chief conclusion of our study can be conveyed in the form of two theses: (1) It is very likely that some zero-value quantities exist and are exemplified by microobjects; (2) Zero-value quantities exist (if they do) in precisely the same sense as nonzero ones. They are not mere absences, privations or "holes in being". They possess a most robust degree of reality, on a par with their non-zero partners. This, I believe, is not what one would expect based on common-sense intuitions. Quantity, as we have known since Aristotle, is a measure of presence. And what is "zero presence" but absence? It won't do to conceive of a zero-value physical quantity as a limiting case of a converging series of its non-zero values. This model works well in situations where the limiting case is itself unattainable and the only way to get a handle on it is to envisage a sequence of approximations to it. But zero-value physical quantities discussed above (i.e., spin, charge, etc.) manifest themselves in observable phenomena directly, just like their non-zero companions, and not vicariously, that is, through non-vanishing approximations to zero. It is precisely through those manifestations that they are recognized as such.

It may be interesting to compare again zero-value physical quantities with *holes*. The latter are created and destroyed, they move, partition, and coalesce. They are quantified over and, arguably, cannot be completely paraphrased away (Casati and Varzi 1994). But they do not exist on their own, without their "hosts" (in which they are holes). Zero-value quantities, on the contrary, subsist, in certain cases, by themselves, unbacked by more fundamental non-zero quantities, and they can, in a sense, be "touched" and "seen" (with the aid of powerful accelerators and sensitive detectors) in a way holes cannot.

What must these entities be like in order for this to be possible? I shall not attempt here a full inventory of questions that the ontological nature of zero-value quantities might raise. But I find it useful, in conclusion, to bring their probable existence to bear on a dispute between two major views of property, *dispositionalism* and *categoricalism*.

Extreme dispositionalism identifies the nature of all properties with their actual and possible manifestations.[19] Categoricalism, on the other hand, regards properties as self-contained entities "keeping themselves to themselves, not pointing beyond themselves to further effects brought about in virtue of such properties" (Armstrong 1997, 80).[20] These effects are thought by some categoricalists to have their ontological ground in two sources, a categorical property itself *and* a law of nature relating (as in the Dretske–Tooley–Armstrong theory[21]) this property to another equally categorical property. Dispositionalists complain that such a scheme cannot adequately account for the modal force of natural laws (and confronts other problems as well) and argue that the laws of nature are best construed as deriving from the ascription of irreducible dispositions to fundamental natural kinds of individuals.[22] Extreme dispositionalism can be moderated by allowing for some genuinely categorical properties, the most plausible agreed-upon candidates being spatial and temporal ones.

It is worth emphasizing that most dispositionalists and categoricalists, despite their opposite views on the nature of property, endorse the empirical approach to it. Thus Armstrong (1997, 25), a paradigm categoricalist:

> Although universals are here upheld, they are not upheld, as many have upheld them, in order to give semantic values to general words and phrases. Universals are here postulated, in the main, in order to explain the resemblances and differences that we find among particulars, beginning with our perception of particulars in our environment. This perceptual acquaintance with the natures of particulars is extended, deepened, and in many ways corrected by the whole great enterprise of natural science .... It is to natural science, then, that we should look for knowledge, or perhaps just more or less rational belief, of what universals there are. Hence the term "*a posteriori*" realism. The theory of universals may have to be developed in an *a priori* manner. But the theory of what universals there are must be an *a posteriori* matter.[23]

Ellis, a paradigm dispositionalist, writes (1996, 14):

> There are properties which have no names, e.g., because they have yet to be discovered, and there are predicates which truly apply to things, but which do not name properties. The question, therefore, arises: which predicates designate properties? I do not think that this question can be answered *a priori*. ... If properties exist independently of language, then it cannot be the case that we can discover new properties just by the artful manipulation of language. New properties have to be discovered in nature, not inferred from the predicates we use to describe things.

A major issue that divides dispositionalists and categoricalists is whether one should drive a "metaphysical wedge" (the expression is Ellis and Lierse's (1994, 30)) between *what* things are and *how* they behave.

In the opinion of most categoricalists, things are what they are in virtue of their categorical properties, and they behave how they do partly in virtue of such properties, and partly owing to particular laws of nature. Laws, on this view, are contingently imposed upon entities whose specific identity is quite independent of them. One and the same kind of thing, say the electron, can submit to different laws in different worlds. Dispositionalists argue that this view is fundamentally mistaken and resort for support to modern science. They concede that the separation of the nature of things from their behavior might be, to some extent, legitimate in the macroworld, where we deal with complex structures composed of more elementary constituents. Where such a structure, say common salt, is present, its dispositions, such as solubility, at least partly derive from the arrangement of the elements, and such an arrangement appears to be a categorical property of the structure. When we get down to the most basic physical entities, however, we no longer find any structure to lean back on and must recognize irreducible dispositions as properties that ground both the behavior and the nature of fundamental objects. Their behavior is, in fact, indistinguishable from their nature. What makes something an electron, for example, is precisely a set of dispositions to behave and to interact with other such entities in specific ways. Nothing could be an electron without behaving like one. On this view, the fundamental laws of nature, rather than being imposed "from above", naturally arise from "bottom up". They emerge from irreducible dispositions of the basic individuals and confer on them precisely the kind of necessity the laws of nature are usually assumed to possess (Bigelow et al. 1992).

This is surely a strong point and it conforms to the way particle physicists conceive of their subject matter. Categoricalists, however, remain unpersuaded and insist that every disposition regarded by dispositionalists as irreducible, including those of the fundamental physical individuals, can and must be viewed as a joint product of a certain categorical basis and a contingent law of nature. Of course, it not an easy task to produce a realistic example of such an underlying categorical basis when the matter concerns electrons and quarks, rather than things like salt and iron. Whereas dispositionalists can simply help themselves to a contemporary scientific theory in referring to properties they take to be fundamental and irreducible – properties such as spin and charge, as well as various dispositions of a fundamental entity to interact with other equally fundamental entities, as prescribed by the Lagrangian of a given theory – categoricalists have to assume that physics cannot, in this case, be a reliable guide to ontology. Categoricalists, however, are convinced that dispositionalism fails on more general grounds, that the idea of an irreducible disposition does not stand the weight of objections that can be brought against it.[24]

The debate is going on,[25] but is not my purpose here to engage in discussion of questions already raised by it. Instead, I want to add a new issue to its agenda, the issue of zero-value physical quantities. It is clear that if such quantities exist, as argued in this paper, they could easily be construed as irreducible dispositional properties. Our entire discussion revolved around delineating important physical traits, either uniquely associated with a certain zero-P-hood or shared by zero-P entities with their non-zero-P partners. Such traits are of the nature of dispositions. They can be thought of as manifestations of a set of dispositional properties which includes the property *zero-P-hood*. Consider, for example, a spin-0 scalar boson. Because of this property, it exhibits various physical traits. In particular, it obeys Bose–Einstein statistics (thus sharing this trait with spin-1, spin-2, and other integral-spin objects) and has only one polarization state in all physical situations. That zero-spinhood is a really existent property should not surprise the dispositionalist, because its existence just amounts for her to specific traits in the behavior of entities possessing this property.

Not so for the categoricalist. How would she conceive of zero-P-hood? One begins to sense trouble here. On the categoricalist view, zero-P-hood must qualify an object regardless of any effects or traits that might be conferred by this property. There must be, so to speak, some "metaphysical stuff" of which P-hood is composed, the stuff whose nature is independent of the way P-entities behave. And there must be a determinate property characterized by strictly *zero amount* of that "P-stuff". What is crucial, of course, is that in light of the arguments advanced in the main part of the present paper, this zero amount of P-stuff cannot be a mere absence but must, on the contrary, share the full degree of existence with non-zero amounts of the same "stuff". But clearly, the concept of zero amount of something *as distinct* from that of the absence of any non-zero amount of the very same thing, defies understanding. The categoricalist is ill-equipped to make a distinction here – a distinction backed up, as we have seen, by a real difference in physical behavior. This pictorial way of speaking may, of course, bear but a metaphorical relation to the real ontological situation. But, I think, enough has been said to raise a suspicion that something may be wrong with zero-value quantities when these are categorically construed and to invite the categoricalist to tell a more plausible story about them.

I shall finish the paper by considering two such possible stories. The categoricalist might point out that she is not committed to any "linear" or otherwise simple relationship between the value of P and the amount of metaphysical P-stuff. After all, she did not claim that any allegedly dispositional property is in fact categorical. What she did claim was that any allegedly irreducible dispositional trait must be reducible to a categorical basis and a law of nature. There may, in other words, exist an intermediate link between the value of P, dispositionally understood, and the measure of the categorical stuff, call this stuff *CAT*, and this link may be supplied by a corresponding law of nature. Speaking for the purpose of argument metaphorically again, call the measure of this *CAT*-stuff C. The idea now is that, because of the mediation of a law of nature, the relationship between the P-scale[26] (where a particular value of P is assigned according to dispositions of a P-entity to behave in certain ways) and the C-scale (C measured by the amount of the categorical *CAT*-stuff) may be far from simple. For example, the scales of P and C may be "shifted" with respect to one another so that $P = 0$ correspond to $C = C_0 > 0$ and $P > 0$ correspond to $C > C_0$. In short, what looks, dispositionally, like a $P = 0$ quantity may be a joint product of an $C \neq 0$ categorical quantity and a law of nature (relating, for example, property *CAT* to another categorical property, as it does in the Dretske–Tooley–Armstrong theory). The categoricalist could thus avoid the difficult task of making sense of the zero amount of P-stuff because she could deny that there is P-stuff. She could insist that there is, instead, a non-zero amount of *CAT*-stuff plus a law working together to produce a physical trait described dispositionally by assigning $P = 0$.

An objection to this strategy is that, although it might work for some zero-value quantities, it will not work for all of them. It might, in particular, work for quantities that can only take positive and zero values (for example, the absolute value of spin). But consider quantities such as charge, which can take negative values as well. What value of C will correspond to $P < 0$? Symmetry considerations, deeply rooted in the physics of the matter, require $C < 0$. This already presents an obstacle, for it is difficult to make sense of a negative amount of *CAT*-stuff. But let us suppose, for the sake of argument, that $C < 0$ could be suitably reinterpreted in some other way, say, as a *positive* amount of "–*CAT*-stuff".[27] Now let P approach zero "from the right" and "from the left". C will have to match this by approaching C_0 and $-C_0$. What value of C will correspond to $P = 0$? Clearly, there are only three options: C_0, $-C_0$, or both – none being acceptable. C_0 and $-C_0$ are excluded by symmetry considerations (neither of them is any better than the other, so there is no sufficient reason for prefering either) and "both" is, as they say, repugnant to intellect.

Ned Hall has suggested[28] another way of handling the problem, on behalf of the categoricalist. Instead of postulating a "doublet" of *CAT*- and $-$*CAT*-stuff (related by a metaphysical analog of "charge conjugation" transformation), the categoricalist could introduce two *distinct* property-stuffs, CAT_1 and CAT_2, to account for the whole range of P, including its zero value.[29] Suppose one allows CAT_1 and CAT_2, to be metaphysically coinstantiated. But when so coinstantiated, CAT_1 and CAT_2, as a matter of nomological but not metaphysical necessity, *counteract* each other. One can then draw a nomological connection between a certain $P \neq 0$ and $C_1 - C_2 \neq 0$. A similar connection would then exist between $P = 0$ and $C_1 - C_2 = 0$. The categoricalist would now have the resources needed to distinguish the case of $P = 0$ from the case of complete P-lessness. She would say that the former involves coinstantiation of CAT_1 and CAT_2 in exactly counterbalancing amounts, whereas the latter involves the instantiation of neither CAT_1 nor CAT_2.

These resources, however, are purchased at a considerable cost of parting ways with science. First, where science allows but a single property P taking negative and positive, as well as zero values, the categoricalist invokes two distinct property stuffs, CAT_1 and CAT_2. Second, she has to admit an infinity (and in some cases, a continuum) of distinct metaphysical states of affairs that are nomologically indistinguishable: a given value of P could be grounded in any pair of C_1 and C_2 satisfying $C_1 - C_2$ = const. Third, the story will have to be further elaborated to handle properties such as color charge to account for the fact that *three* different colors can combine to produce a zero-color combination.

Although none of these difficulties formally refutes the story, it would appear that the *scientifically-sensitive* categoricalist should be sufficiently troubled by them.

NOTES

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[1] I leave it open whether some or all microphysical properties give rise to interesting questions about their zero values. It is sufficient for my purposes that some clearly do. Also, in this paper I attempt no general criterion or principle for selecting "interesting" micro-properties. I do believe, at the same time, that spin and charge-like properties of elementary particles are the best candidates and provide, in Sections 6 and 7, some reasons for thinking so.

[2] Do we have such intuitions about zero values of more mundane properties present in the manifest image of the world? As noted, unambiguous intuitions abound in trivial cases of relational properties or derivative ones that are constructed in such a way as to include zero value on a par with others. This tells one something about the manner of construction and little, if anything, about the intrinsic nature of zero-value properties. Exceptions are very few. Duration appears to be a non-relational and non-derivative property of events and processes. Is zero duration a duration? Well, one has yet to produce a real-life example of an event having zero duration (or no duration at all, as the case may be). The situation is different from (although it naturally invites comparison with) the case of *holes*, which has recently received attention. Holes are undoubtedly given in experience and one could argue, based on various intuitions about holes, that they exist (Casati and Varzi 1994). In the absence of experienced zero-duration events, the best one can do is to appeal to imagination and analogy, and these bring with them a host of metaphysical predilections. It might also be tempting to draw a parallel between the issue of zero-value physical quantities and a much-debated (e.g., by Husserl and Frege) question of the status of the number zero in the philosophy of mathematics. Rather than pursuing this line, however, I hasten to note an important disanalogy. Number zero either exists (on a par with other numbers, if they themselves exist) or it does not. But different candidate zero-value physical quantities may well find themselves on different sides of the barricade: some of them may prove to be existent and others may not – another reason to proceed empirically, as suggested below.

[3] See Oliver (1996) for a recent review of the metaphysics of properties.

[4] I am in general sympathetic with Lewis's idea of privileging a certain family of properties (hence, a certain family of sets of possibilia) as "natural" ones (Lewis 1983; 1986, §1.5). Such properties figure prominently in various conceptual analyses and, unlike "unnatural" properties, are capable of accounting for complete intrinsic similarity (duplication) among particulars. Naturalness comes in degrees: the set of green things is more natural than the set of grue ones, just as the set of apples is more natural that the set of apples mixed with oranges. Physics may be a discipline qualified par excellence to provide an inventory of perfectly natural properties (Lewis 1983, 356–7, 365). Thus if physical considerations favor a distinction (as I hope to show in subsequent sections) between *a*-entities having zero-value of some fundamental property and *b*-entities having no such property at all, then the set of *a*-entities would be more natural than the set comprising both *a*- and *b*-entities. To the extent that the Lewisian is willing to acknowledge a firm connection between science and an account of what properties there are, she could, I believe, benefit from my analysis. On the other hand, as long as properties are taken to be just sets and nothing more, it is hard to see what is really gained by labeling certain sets as "natural".

[5] The term coined by Swoyer (1993).

[6] The literature defending the empirical conception of property is quite extensive. The following is a sample list: Putnam 1975; Armstrong 1978, 1997; Shoemaker 1998; Wilson 1982; Swoyer 1993,1996; Ellis and Lierse 1994; Ellis 1996; 1998. For criticism of the empirical conception, see, e.g., Oliver 1996.

[7] Cf. Mill's Joint Method of Agreement and Difference: "If two or more instances in which the phenomenon occurs have only one circumstance in common, while two or more instances in which it does not occur have nothing in common save the absence of that circumstance; the circumstance in which alone the two sets of instances differ, is the effect, or cause, or a necessary part of the cause, of the phenomenon" (Mill 1885, 229).

[8] Such are, for example, the familiar pions: $\pi^{\pm}$ $(u\bar{d}, d\bar{u})$ and π^0 $((u\bar{u} - d\bar{d})/\sqrt{2})$. Here u and d are "up" and "down" quarks, $\bar{u}$ and $\bar{d}$ the corresponding anti-quarks. See also Table 1.

[9] The quark-gluon structure of the baryons can actually be "observed" in deep inelastic scattering experiments. See Section 7.1 for more details.

[10] Namely, the state characterized by the zero value of spin along the particle's direction of motion.

[11] My exposition of the relevant details of the WSG theory here and in Section 7.1 follows Collins et al. (1989, Ch. 4). For an elementary but still very illuminating account see Moriyasu 1983.

[12] That is to say, there is no reason to believe that the masses of fundamental particles are multiples of a common unit.

[13] In Armstrong's view, supervenience equally applies to objects (particulars) and their properties (universals): "Q supervenes upon P if and only if there are P-worlds and all P-worlds are Q-worlds" (1997, 11), where 'Q' and 'P' may stand for objects or properties. Given that supervenience is an intensely disputed topic and that various notions of supervenience have been carefully distinguished and opposed in the literature, Armstrong's blanket approach seems to be an oversimplification. Nonetheless, it suffices for his purposes and is relevant to the present discussion.

[14] Here $\tau_k \equiv \sigma_k$ (k = 1, 2, 3) are Pauli matrices,

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix},$$

serving as generators of SU(2) with Lie algebra $[\tau_k, \tau_l] = 2i\epsilon_{klm}\tau_m$

[15] A particle is called "right-handed" ("left-handed") if its spin, projected on the direction of motion, is parallel (anti-parallel) to its velocity. Electrons occur in both right-handed and left-handed states whereas all electron neutrinos are left-handed.

[16] "Zero color" can be obtained in two different ways: (1) by forming a meson-type bound state of a quark and an anti-quark, the former carrying a positive unit of some color (say, red) and the latter a negative unit of the same color; (2) by forming a baryon-type bound state involving three quarks of different colors (red, green and blue) producing a neutral ("white" or "zero") net color.

[17] This claim will have to be qualified if the hope of uniting strong and electroweak interactions is eventually fulfilled. There is general belief that these two kinds of interaction are manifestations of a single force of nature. There are also many proposals as to how to construct a theory effecting such a unification but no empirically adequate theory elaborated to an extent comparable to that of the electroweak theory and quantum chromodynamics (i.e., the theory of strong color interactions) taken separately. More on this below.

[18] A corresponding property possessed by leptons and lacked by baryons, called *lepton number*, can be analyzed along the same lines.

[19] Such a position has, for example, been defended by Mellor (1974).

[20] An intermediate position advocated by Martin (see Armstrong et al. 1996, 71–87) holds that every property has a categorical, as well as a dispositional, side, no property being fully categorical or fully dispositional.

[21] For a brief account of that theory, see Armstrong 1997, Chs. 15 and 16.

[22] For arguments, see Bigelow et al. 1992; Ellis and Lierse 1994; Ellis 1996, 1998.

[23] In an earlier work, Armstrong expressed his credo in still stronger terms: “If it can be proved *a priori* that a thing falls under a certain universal, then there is no such universal” (1978, 11).

[24] See, in this connection, Swinburne 1983; Armstrong 1997, Chs. 5 and 16, 1999.

[25] The interested reader is advised to consult Armstrong et al. 1996; Mumford 1998,; Armstrong 1999 and references therein.

[26] Or P-serial order, in case of a discrete physical quantity.

[27] Such a move might, for example, be suggested by considerations akin to those invoked by Dirac in the late twenties, when he reinterpreted the negative-energy solutions of his relativistic wave equation for the electron as *positive*-energy states of the “negative electron”, later identified with the positron.

[28] In his comments on the APA version of this paper.

[29] Another historical parallel is readily available: in the pre-modern period, two distinct sorts of “electricity” stuff, the positive and negative ones, were believed to stand behind the whole range of electric phenomena.

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