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Quantum Field Theory and Zubiri's Philosophy of Reality[1]

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Abstract

The nature of reality as revealed by the most modern science is compatible with Zubiri's philosophy, but less so with traditional philosophies. This vindicates Zubiri's view of reality as formality rather than a zone of things, and his view that progression is a search not just for new things but also for new forms and new modes of reality." Zubiri understood well the quantum theory developed by his friend Werner Heisenberg and others in the first decades of the 20th century. He recognized that this new theory of physics brought with it new modes of reality, such as that of elementary particles, neither waves nor bodies exclusively, which do not fit into classical philosophy and are not visualizable in any ordinary sense. But newer developments, especially Quantum Field Theory, have continued in quite unexpected ways and revealed still more forms and modes of reality that had not been suspected. The nature of these modes suggests that the boundary between the physical and the mathematical is blurring, all of which can be accommodated in Zubiri's thought, but which is devastating for much of Western philosophy, especially Hume and Kant, and actually favors a more Platonist view. This includes virtual particles that have non-physical properties: negative energy, negative momentum (momentum opposite to velocity), off-shell mass values, speeds greater than light; gauge fields that are more real than ordinary fields, but less measurable; internal symmetry spaces that allow calculations but are otherwise non-real; and symmetry principles in which reality seems to "partake". Quantum Field Theory also moves away from the problematic action-at-a-distance notion of classical fields, to a more traditional causality requiring contiguity, but with many important differences from the classical view. The nature of the scientific method as understood on the basis of Zubiri's philosophy changes somewhat with these new developments. However Zubiri's analysis of science and scientific reality can handle these changes.

Resumen

La naturaleza de la realidad tal como lo revela la ciencia más moderna es compatible con la filosofía de Zubiri, pero no tanto con las filosofías tradicionales. Esto justifica la opinión de Zubiri de que la realidad es formalidad en vez de una zona de las cosas, y su opinión de que "la marcha es una búsqueda no sólo de nuevas cosas reales sino también de nuevas formas y de nuevos modos de realidad." [2] Zubiri entiende bien la teoría cuántica desarrollada por su amigo Werner Heisenberg y otros en las primeras décadas del siglo XX. Reconoció que esta nueva teoría de la física trajo consigo nuevos modos de realidad, como el de las partículas elementales, ni olas ni corpúsculos exclusivamente, que no encajan en la filosofía clásica y no son visualizables en el sentido ordinario. Pero los nuevos desarrollos, especialmente la Teoría cuántica de campos, han continuado en formas inesperadas y nos han revelado aún más formas y modos de realidad que no se había sospechado. La naturaleza de estos modos sugiere que la frontera entre la física y la matemática se está

desdibujando, todo lo cual puede ser alojado en el pensamiento de Zubiri, pero resulta devastador para gran parte de la filosofía occidental, especialmente la de Hume y Kant, y de hecho favorece una visión más platónica. Esto incluye las partículas virtuales que tienen propiedades no físicas: la energía negativa, el impulso negativo (impulso opuesto a la velocidad), los valores de masa fuera de la capa, una velocidad superior a la luz; los campos de norma que son más reales que los campos comunes, pero menos medibles; los espacios de simetría interna que permiten cálculos, pero que en otro sentido son no reales; y los principios de simetría de los que la realidad parece "participar". La teoría cuántica de campos se aparta de la noción problemática de "acción a distancia" de los campos clásicos, acercándose a una causalidad más tradicional que requiere la contigüidad, pero con muchas diferencias importantes respecto del punto de vista clásico. La naturaleza del método científico, tal como se entiende sobre la base de la filosofía de Zubiri, cambia un poco con estos nuevos desarrollos. Sin embargo, el análisis de Zubiri de la ciencia y la realidad científica puede manejar estos cambios.

Introduction: Philosophy and Science

Philosophy is not an empirical science, like physics or chemistry. But it does have an empirical basis, because philosophy is ultimately knowledge of reality, and science acquaints us with reality, especially aspects of reality that are not part of ordinary experience. All philosophies—all philosophical systems—take as their starting point some aspect of our experience, and build upon it to create a comprehensive view of reality. Plato, for example, started from our perception of qualities such as beauty; and because what we perceive is always less than perfect but nonetheless exists in degrees, inferred that there must be an ideal realm where beauty in its most perfect form subsists. Objects in our world "partake" of this beauty. Aristotle started from common notions such as causality and change, and built what we now term "classical philosophy". Kant famously started from Hume's empiricism but perhaps even more importantly, from Newtonian physics, making it an essential part of his philosophy. The problem of course is that if subsequent developments in our knowledge—mainly through science—invalidate or supercede the empirical basis assumed by the philosopher, his entire system can collapse. Aristotle's theory of substantial change, involving a return to prime matter and a new form, is not compatible with modern atomic theory. Non-Euclidean geometry and its inclusion as part of General Relativity essentially destroyed Kant's philosophy, because it showed that reality is not ultimately Euclidean and that we can consistently understand reality in non-Euclidean terms. Thus Euclidean geometry cannot be how we synthesize experience. This implies that any new philosophy must be extremely robust with respect to possible advances in science, as well as incorporating what science has already taught us about reality. Zubiri understood this well, so we shall examine how his philosophy is able to handle ideas in physics that were not envisioned during his lifetime, or were only vaguely understood then.

The purpose of this paper is to show that the nature of reality as revealed by modern science is compatible with Zubiri's philosophy, but less so with traditional philosophies. It also shows that the scientific method, as constructed based on Zubiri's philosophy, is still valid under the newest physics, though with one change. This vindicates Zubiri's view of reality as formality rather than a zone of things, because modern science, in particular quantum theory but especially Quantum Field Theory (QFT), has revealed new modes of reality that had not been suspected, and which are not real in the sense of macroscopic bodies or even the particles and waves of quantum mechanics. The nature of these modes suggests that the boundary between the physical and the mathematical is blurring, which is devastating for much of Western philosophy, especially Hume and Kant, and actually favors a more Platonist view.

Modern physics and Zubiri's philosophy of reality

Zubiri was well acquainted with quantum mechanics, as developed by Bohr, Heisenberg, Dirac, Pauli, and others. Heisenberg, in particular, was his friend. So he recognized the significance of the new ideas such as the wave/particle duality:

> In the most elemental field of reality we have intellectively apprehended that the material things in it are what we term 'bodies'. In the progression beyond the field it has been thought for many centuries that the things "beyond" are also bodies—of another class, to be sure, but still bodies. It required the commotion generated by quantum physics to introduce in a difficult but undeniably successful way the idea that the real beyond is not always a body. Elementary particles, in fact, are not corpuscles (neither are they waves in the classical sense, be we leave aside this aspect of them) but another class of material things. Borne along by the field intellection of things, we were disposed to intellectively know the things beyond the field as bodies, different perhaps, but when all was said and done, still bodies. The measure of the real was undertaken with a determinate metric: "body". Now, the progress toward reality has opened up to us other real material things which are not bodies.[3]

But stranger ideas have come from QFT, such as virtual particles, gauge fields, isospin, and internal symmetries, all of which stretch our notion of what is real in the sense of empirically observable, but which are in some ways more real than what is empirically observable. First let us examine these notions, and then explore how they fit with Zubiri's understanding of reality, causality, and knowledge.

Gauge fields and gauge symmetry

Gauge fields are essential to modern physics, but are very peculiar "entities", for want of a better term. They began as ways (auxiliary fields) to express constraints, but soon took on a life of their own. The simplest example of a gauge field is the vector potential **A**, defined with respect to the magnetic field vector **B**. One of Maxwell's equations is $\nabla \cdot \mathbf{B} = 0$. Whenever the divergence of a vector field is zero, it immediately follows that the field—**B** in this case—is the curl of another field; that field is always called the "vector potential", **A**, with defining equation $\mathbf{B} = \nabla \times \mathbf{A}$. Thus the vector potential **A** expresses the constraint on **B** that its divergence must be zero. What is especially significant about **A** is that it is not uniquely determined: one can add the gradient of any scalar function to it and its defining equation is unchanged, because if $\mathbf{A}' = \mathbf{A} + \nabla f$, we have

$$\mathbf{B} = \nabla \times \mathbf{A}' = \nabla \times (\mathbf{A} + \nabla f)$$
$$= \nabla \times \mathbf{A} + \nabla \times \nabla f = \nabla \times \mathbf{A}$$

since the curl of a gradient is always zero. Susskind notes:

> The vector potential is a peculiar field. In a sense it does not have the same reality as magnetic or electric fields. Its only definition is that its curl is the magnetic field [**B**]. A magnetic or electric field is something that you can detect locally. In other words, if you want to know whether there is an electric/magnetic field in a small region of space, you can do an experiment in that same region to find out…But vector potentials cannot be detected locally.[4]

Moreover gauge fields such as **A** go far beyond mere computational devices. Experiments can be devised that show (very indirectly) the presence of the **A** field using the Aharonov-Bohm effect, where no **B** field exists.[5] Furthermore, we cannot do physics without them:

> There is no way to derive Lorentz's force law from a Lagrangian without the vec-

> tor potential [**A**]. This is a pattern: To write the equations of modern physics in either Lagrangian or Hamiltonian form, auxiliary gauge fields have to be introduced…Gauge fields cannot be "real," because we can change them without disturbing the gauge invariant physics. On the other hand, we cannot express the laws of physics without them.[6]

So the gauge fields such as **A** are in a sense more real than fields we can actually measure, such as **B**. This is hard to explain on the usual view that reality is a zone of things, but is readily understandable on the basis of Zubiri's philosophy: "The real is not a 'thing' but something 'in its own right', thing or not"[7].

Virtual Particles and Causality

Zubiri was well acquainted with quantum mechanics and the ways in which it revised our notions of physics and reality from classical mechanics. As noted above, he noted that in quantum mechanics we learned about forms of reality that are not "bodies" in the classical sense. Zubiri also recognized that with quantum mechanics, we have moved beyond visualizability as a criterion for scientific reality:

> …elementary particles are realities, since they are given a splendid mathematical description in quantum mechanics. Nonetheless, they are not visualizable as if they were waves or particles. Their real structure is such that they are emitted and absorbed as if they were corpuscles and they propagate as if they were waves. But they are neither. And it is not just that in fact we do not see these particles, but that they are in themselves realities which are "non-visualizable". And…the identification of the visible and the intelligible is philosophically false: every intellection is sentient and, therefore, every mode of apprehension of the real—even if that reality be neither visual nor visualizable—is true intellection, and what is apprehended therein has its proper intelligibility.[8]

QFT and related developments have shown us that there are forms of reality beyond those conceived by quantum mechanics. In addition, QFT gives us better insight into the problem of causality. Traditionally causality was assumed to require a contiguous, efficient cause. This made explanation of inertial movement, such as that of a stone that has been thrown, very difficult: there is no contiguous efficient cause. Even worse was the problem of action at a distance, which came to the fore with Newton's laws and his theory of gravity. How could the earth cause instantaneous changes in the motion of the moon over a distance of 400,000 km? The answer to the first problem was stated by Galileo and incorporated into Newton's laws as the First Law of Motion, the Principle of Inertia: "a body in uniform motion tends to stay in motion unless acted upon by an external force." But this did not really solve the causality problem; it merely affirmed that such causality is not relevant. It was not until Einstein and his application of symmetry that we understood why it is not relevant: there are no privileged reference frames in the universe. What looks like motion to one observer looks like different motion to another, or no motion at all. No causal explanation is needed because we are just looking at a symmetry of nature.

The second problem proved more difficult. Faraday first recognized that sources of electric and magnetic force created "fields" in space. In classical physics, and even relativistic physics, a field is an entity which has a value at each point in space and time, and which is capable of exerting a force on particles as a function of its value where the particle is, and the relevant "charge" on the particle (e.g., electrical or gravitational). Thus any suitable object that ventures into the volume of space where the field exists would experience a force proportional to its "charge" with respect to that field. Maxwell showed that these fields are not instantaneous, but propagate at the speed of light; and this idea was extended to gravity: the earth sets up a gravitational field, felt by the moon. Einstein later refined the idea of a gravity field, replacing it with the notion of a warped spacetime fabric. But how this fabric interacts with bodies was left somewhat obscure.

QFT solved the problem by a return, in a sense—but only in a sense—to the idea of contiguity. In QFT, a field does not have the function of exerting a force on objects; rather, the field merely creates *virtual particles* which mediate the force, i.e., transfer energy and momentum between the particles. That is, the virtual particles are force carriers. They are called "virtual" because they are not observable even in principle without disrupting the interaction between the particles and in fact can have non-physical properties, such as travelling faster than light, or negative momentum (momentum in opposite direction to velocity). Moreover the interaction between real particles, mediated by the virtual particles, is the result of the sum of probabilities of *all possible ways* in which the virtual particles can travel between the real particles. Figure 1, from Feynman, shows some of the possible paths a photon can take in going from point S to point P, reflected off of a mirror. The amplitude at point P is the sum of the amplitudes of all the paths, as determined by their phases, which add as shown at the bottom of the figure. Only those paths near the center have phases which are close in value and hence add; those further away are random and cancel. Thus we say that the light takes the shortest path—the usual law of reflection, even

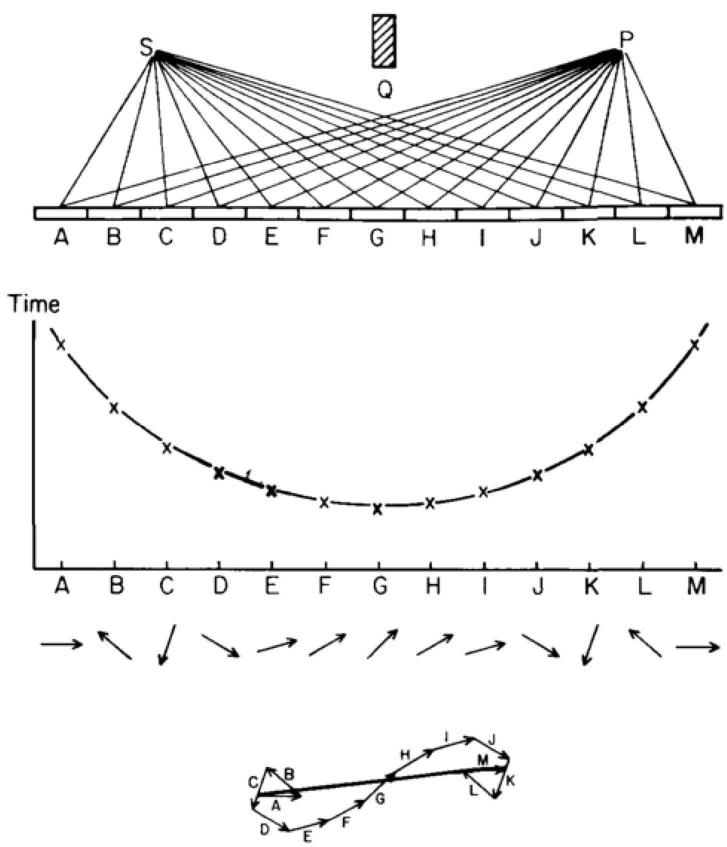

Figure 1. Possible photon paths in mirror reflection

though in reality it takes all paths simultaneously but most of them cancel out. Likewise In the case of interactions, all possible exchanges of virtual particles can occur, an infinite number, some of which are shown in Figure 2, for Compton scattering (interaction of a photon and an electron). The first two diagrams show the basic interaction of the photon and the electron. The remaining figures show the alternative ways of interaction. The more loops, the less probable the interaction, but all must be summed to get the total probability of the interaction occurring. Figure 3 shows the interaction of an electron and a positron, which annihilate in a burst of energy as a photon (indicated with k in the diagram), the virtual particle, which subsequently creates another electron and positron (Bhaba scattering). As before there is the basic interaction, and an infinite number of variants, only a few of which are shown. It is never possible to observe the virtual particles without completely disruption the interaction, i.e., creating a new and different interaction that now involves the observer.

As described above, the virtual particles, the gauge bosons, have some rather peculiar characteristics: they "take" an infinite number of paths between the particles simultaneously, each with a certain probability; and they can assume non-physical characteristics such as negative momentum and speeds greater than the velocity of light. So we have not really reestablished contiguity because virtual particles are not real in ordinary sense—they have some other form of reality. This has culminated in the *Path-Integral* formulation of much of physics, pioneered by Dirac and especially Feynman, based on earlier work by Fermat.

If reality were a zone of things, we could not put virtual particles and symmetry principles in it, and we certainly could not explain the path integral formulation of physics, with the "same" particle taking an infinite number of paths between origin and destination. But virtual particles and symmetry are real, though in a different way than even the waves and particles of quantum mechanics. We have taken leave of "thingness" as a criterion of reality, though we started with:

> …the intellection that the real things are bodies, but also and above…that to be real is to be a "thing", in the sense that this word has when one speaks, for example, of "thingness". That was the measure of reality: progression beyond the field was brought about by thinking that the measuring reality is a "thing". An intellection much more difficult than that of quantum physics was needed in order to understand that the real can be real and still not be a thing…that progression is a search not just for new *things* but also for *new forms and new modes of reality*."[9]

The path integral formulation of physics, encompassing Feynman diagrams, definitely represents a new mode of reality.

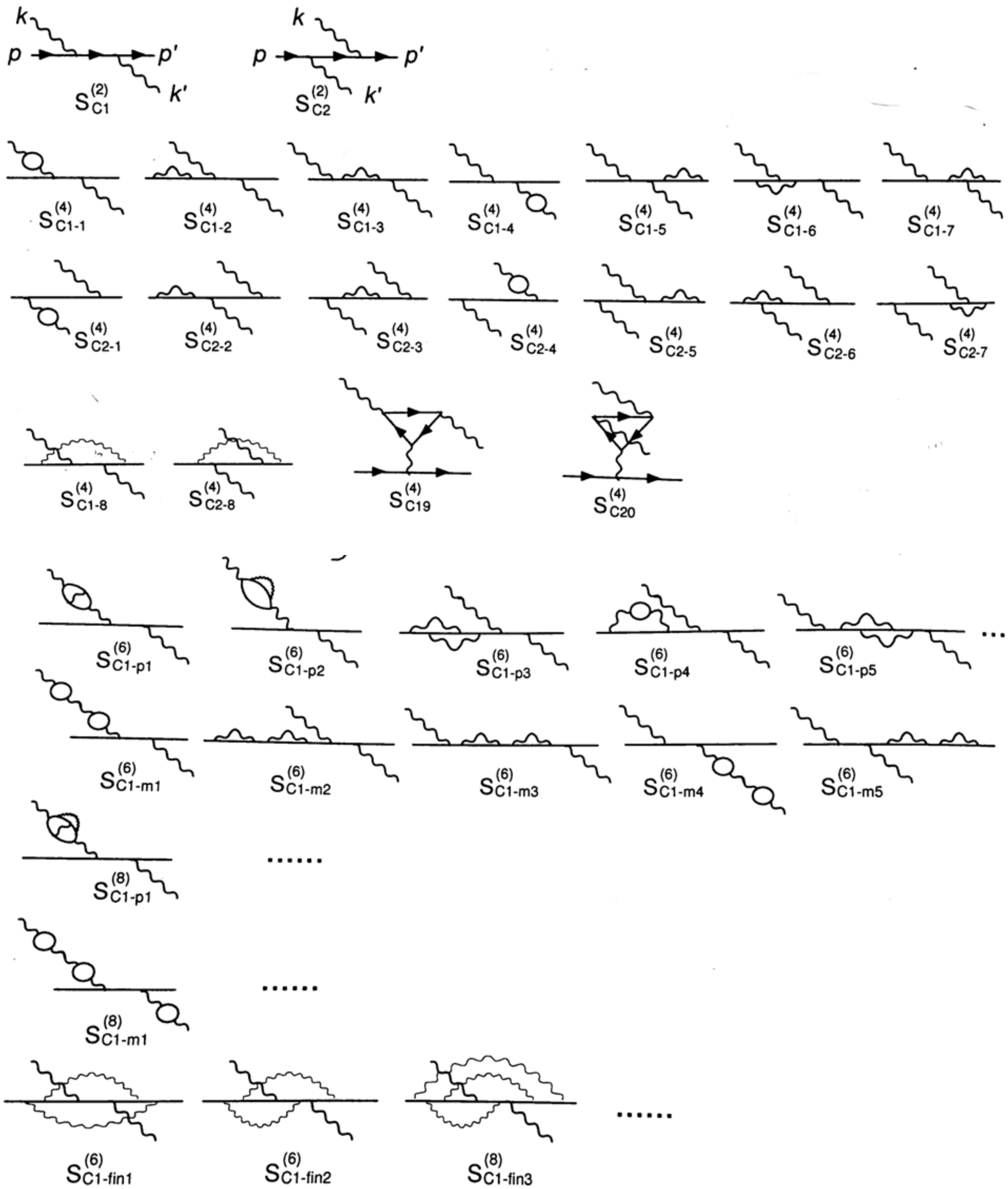

Figure 2. Possible interactions and gauge bosons in Compton scattering.[10]

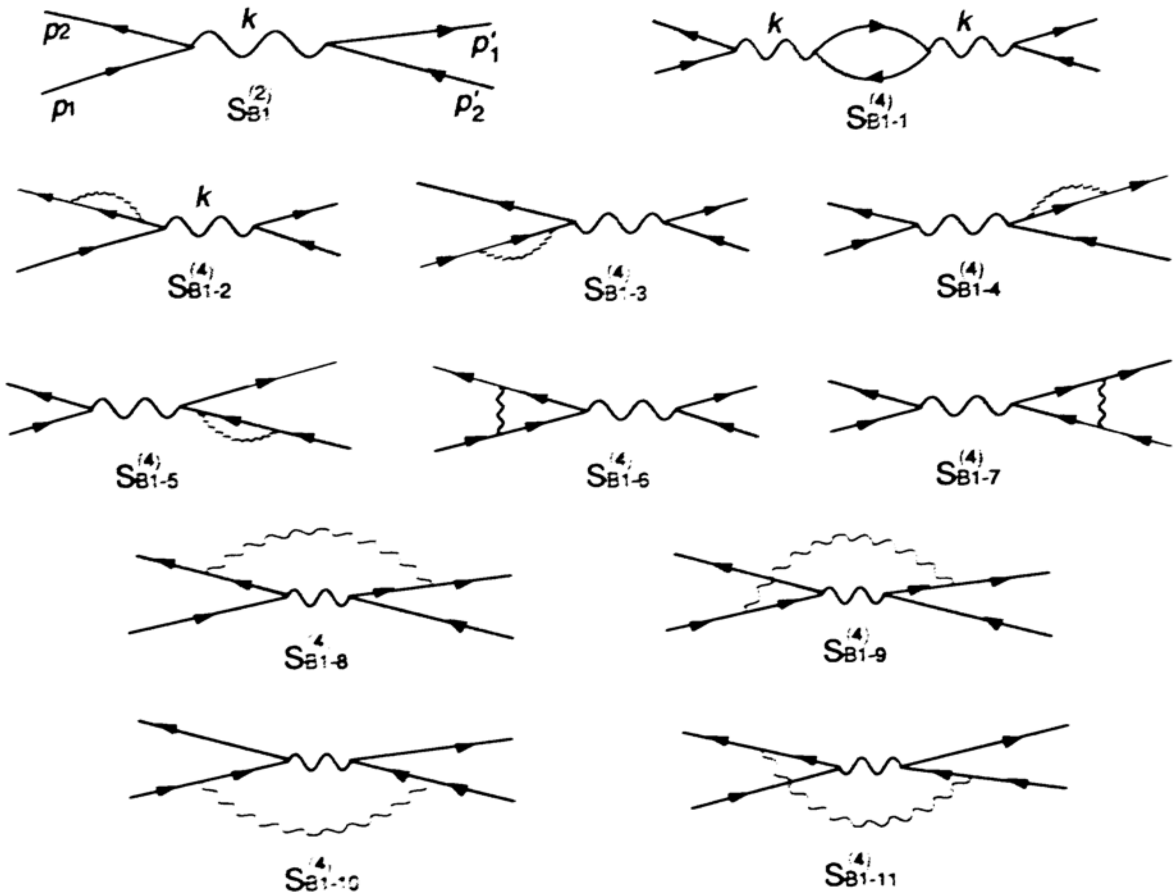

Figure 3. Possible interactions of electron and photon in Bhaba scattering[11]

Isospin

Heisenberg first noted that the similarity between protons and neutrons (they are almost identical except for electric charge) could be explained if we postulate a type of abstract internal space in which one of the two, say a proton, can "rotate" into the other, a neutron. In effect, Heisenberg deduced the presence of a hidden symmetry in nature, called "isospin", and the corresponding abstract space is termed "isospin space". It is not a rotation like those in our normal day-to-day life. Zee comments:

> Isospin represents a stunning landmark in the development of symmetry as a primary concept in physics. Previously, when physicists thought of symmetry, they thought of the symmetry of spacetime. Parity, rotation, even Lorentz invariance and general covariance, are all rooted, to a greater or lesser degree, in our direct perception of actual spacetime. Now, in one sweeping motion, Heisenberg opened up for us an abstract inner space in which symmetry operations can act also.[12]

Isospin symmetry is known by mathematicians as SU(2); it paved the way for further application of symmetry to fundamental physics. Numerous other isospin multiplets are known, including the sigma particles, the pi mesons, and the kappa particles. Essentially we have something non-physical dictating the physical. In Zubiri's terminology, isospin space is real because it has the formality of reality, but it is not, obviously, a body or even normal space, or anything material.

Symmetry

The march away from Newtonian mechanics and determinism, expressed fully by Laplace's Demon, began in earnest with quantum theory, which Zubiri knew, but has continued in quite unexpected ways. In QFT, as noted, virtual particles have non-physical properties: negative energy, negative. momentum (momentum opposite to velocity), speeds greater than light. But especially it is the notion of symmetry that has become of the greatest importance in modern physical theory. It now goes far beyond a description of reality, but in fact acts in a regulatory manner:

> Symmetry forbids. Forbidding imposes order, but many different things that possess a certain order may derive from the same symmetry….That is why physicists believe that the underlying symmetry, which forbids whole classes of occurrences at one stroke, is, in a sense, more fundamental than the individual occurrences themselves, and is worth discovering.[13]

This suggests that we are moving back towards a Platonic view, wherein worldly things "participate" in ideals or forms, specifically, symmetry. One could also take the view—more Aristotelian—that symmetry is a type of formal causality, though how that would work is not clear.

The types of symmetry involved include some approximate symmetries, such as the isospin symmetry of neutrons and protons in isospin space, first recognized by Heisenberg, and exact symmetries. These exact symmetries have become the most important in recent years, with the development of Yang-Mills theories. Historically the Lorentz symmetry was the first to be explicitly formulated, and its importance as a symmetry of nature was recognized by Einstein, who made it the basis of the Special Theory of Relativity. Other symmetries are those in particle physics, which govern what particles of various types there are, and how they are related to each other. Emmy Noether's theorem relating symmetry, conservation, and invariance has further cemented the importance of symmetry in all of physics: whenever there is a continuous symmetry, there is a conserved quantity. And conversely, if there is a conserved quantity, there is a continuous symmetry.

The most important aspect of symmetry is that it is not so much descriptive as prescriptive, which entails a significant change in the orientation of science and in particular, that of the physicist. The 19th and early 20th century paradigm of science, with which Zubiri was acquainted, worked as follows: collect a large body of experimental facts, look for patterns, and find a set of equations that describe those patterns. In Zubiri's terminology, those equations postulate a reality. Then verify the reality—the equations—by devising and performing experiments. In the case of Special Relativity, Einstein realized that the Lorentz invariance of Maxwell's equations (their symmetry) demanded a revision of the laws of mechanics and of the rest of physics as then understood, including our understanding of energy, momentum, and time. The schema is shown in Figure 4:

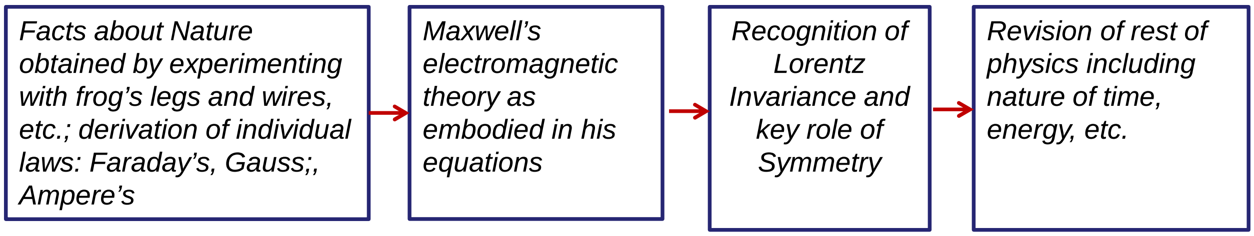

Figure 4. 19th and Early 20th Century Paradigm of Physics[14]

But then physicists realized that the arrows in this schema can be reversed, implying a radical change in reasoning and hence in the way of doing physics:

> After Einstein worked out special relativity, it dawned on him and his contemporary Hermann Minkowski that the arrows in this schema may be reversible. Suppose that it was secretly revealed to us, in the dark of night, that the world is Lorentz invariant. Knowing this, can we deduce Maxwell's theory and hence the facts of electromagnetism, without ever stepping inside a laboratory? To a large extent, we can! The requirement of Lorentz invariance is a powerful constraint on Nature. Maxwell's equations are so intricately interrelated by this invariance that, given one of the equations, we can deduce the others.[15]

In fact Einstein used this approach in his development of the General Theory of Relativity, which describes gravity. Rather than infer the theory in a laborious manner from a collection of disparate facts about the motion of bodies, he formulated a symmetry that was capable of actually determining the theory. The symmetry he used is related to the invariance in the speed of objects falling in a gravitational field. He noted that it is impossible to distinguish between the effect of gravity and that of uniform acceleration—this is known as the "Equivalence Principle"—a key symmetry in nature. As a result the schema he followed is that shown in Figure 5.

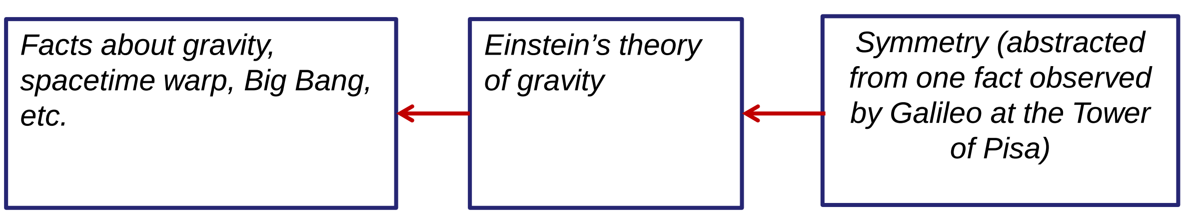

Figure 5. New Way of Doing Physics[16]

This method did not catch on immediately, but by the second half of the 20th century it had become of the utmost importance. As Zee notes:

> I regard Einstein's understanding of how symmetry dictates design as one of the truly profound insights in the history of physics. Fundamental physics is

> now conducted largely according to Einstein's schema rather than that of nineteenth century physics. Physicists in search of the fundamental design begin with a symmetry, then check to see if its consequences accord with observation.[17]

Equally important is the fact that symmetry principles assure us that science is a bona fide exercise:

> …symmetry principles tell us that physical reality, though perceived to be superficially different by different observers, is in fact one and the same physical reality at the structural level…[in the case of isospin] one observer sees a proton, but another observer, whose viewpoint is isospin rotated from the first, may insist that he sees a neutron. They are both right…[18]

As noted earlier, the relativity of uniform motion—essentially the principle of inertia—is also a symmetry of nature. That is, it reflects the same physical reality, so no further explanation of such motion is needed in terms of contiguous efficient causes.

Perhaps more importantly, symmetry principles severely constrain the form the physical laws can take. When Einstein realized that he had to modify Newtonian physics to make it compatible with Lorentz invariance, he did not have a free hand:

> The revision of Newtonian mechanics was not up to Einstein; it is dictated by Lorentz invariance [symmetry]…That the longevity of stars, the magic of light, the compass needle seeking north, and the frog's leg twitching are all interrelated and controlled by one symmetry principle—now that is a real surprise![19]

Symmetry represents a way of measuring reality, in an important sense. Zubiri rightly emphasized the notion of measurability with respect to knowledge of the real, and at one point referred to the "coercive force of the real", which was prescient with respect to symmetry and its role (though the original context was the noetic expression of the force of reality with respect to our impressions).[20]

A summary of the modes of reality and their measurability, based on QFT, is shown in Table 1.

	Mode of Reality					
	Ordinary objects	*Quantum*	*Virtual*	*Phantom*	*Quasi-postulation*	*Postulation*
Measurability	Directly measurable	Measurable subject to limitations (uncertainty principle)	Inferred from effects; characteristic would violate physical laws if directly measurable	Not measurable but physical in some sense	Not physical but real and connected with physical reality	Strictly mathematical
Examples	Macroscopic objects	Subatomic particles-wave/particle duality	Virtual particles	Vector potential, isospin space, weak isospin space, gauge fields	Symmetry	Hilbert spaces, imaginary numbers

Table 1. Measurability and Modes of Reality in Modern Physical Theory

The Scientific Method in Zubiri's Philosophy and Zubiri's Philosophy of Scientific Reality

Two key notions in Zubiri's philosophy of reality with respect to science are that of *canon* and *postulation*. We shall review these briefly.

The Canon of Reality

Zubiri pointed out the key role of the *canon* of reality in his work. Canon comes from the Greek κανον, *rule*. Though introduced much earlier and used by Kant and others, he believes that the original, etymological meaning is the only one that is valid:

> That reality which is already known intellectively is not a medium but a measure, both with respect to what concerns what is real and what concerns that which we call "form and mode of reality". Now, that which is measuring is always reality in the profound sense. But the measurement is always brought about by some particular metric. Reality as the measuring principle is what I term *canon of reality*.[21]

Simply put, the canon of scientific reality is the set of entities usable in scientific explanation or acceptable as outcome or prediction of scientific theory. Knowledge through reason in all its forms involves the canon:

> …reason consists in measuring the reality of things; in it real things give us the measure of their reality. But reason measures reality in accordance with canonic principles which are sensed in the field manner.[22]

So science as knowledge inevitably works by utilizing a canon that is the set of things deemed to be acceptable as objects of science. This is often taken in general terms as "matter and energy". The implication is that the canon can be clearly and unambiguously delineated. However, upon closer inspection, the canon of science or the *canon of scientific reality* is often hazy. For example, in medicine, there is the problem of the interaction of mind and body. What is the mind, and is it real, does it form part of the canon? Are colors naturalistic? What about other psychological phenomena, such sounds, or even dreams? While it might be relatively easy to disregard dreams, colors are more difficult. If we discount or reject colors, we are in danger of rejecting the whole basis for our perception of nature and natural phenomena.

In the 18th century, it was widely accepted that there is a distinction between primary and secondary qualities, and that only the former were really important with respect to nature. In the 19th and early 20th centuries, physicists thought that they had everything pegged with a deterministic billiard-ball model of reality. The idea of things that could be waves under some circumstances and particles under another was not part of their canon. Nor were things that had inherent uncertainties. But even in high-energy physics today, supposedly the hardest of the hardcore science, things are not always so clear. Nobody knows what dark matter is, let alone dark energy, how they may interact with "regular" matter, or what properties they may have. The uncertainty principle made clear that full explanation by means of physical laws, as envisioned by Laplace's Demon, was an unrealizable fantasy, thus delivering a great blow to reductionism.

A review of the history of science readily discloses that science has repeatedly and profoundly changed our view of the world and of reality, and thus affected our canon of reality, as well as affecting the specific canon of scientific reality. The canon of reality allows us to search for new things and new forms of reality. It is thus a guide, but of a particular and essential sort:

> A canon is not a system of normative judgments but is, as the etymology of the word expresses precisely, a "metric"; it is not a judgment or a system of

> judgments which regulate affirmative measurement. This "metric" is just what was previously known intellectively as real in its form and in its mode of reality. The thinking intellection goes off in search of the real beyond what was previously intellectively known, based upon the canon of reality already known.[23]

Successful theories remain as beyond-reality-postulations and the reality they postulate usually enlarges our canon of reality; unsuccessful theories become essentially literary postulations; indeed, "science fiction" as a literary genre is closely related to failed scientific theories. Thus the Theory of Relativity gave us relative space and time, and the speed of light as a universal constant, as well as the equivalence of mass and energy, made famous by $E = mc^2$ and of course nuclear weapons.

Zubiri believes that one of the principal errors of past philosophers was their excessively static view of knowledge—a conquer it "once and for all" approach. Typical of this mentality are the repeated attempts to devise a definitive list of "categories", such as those of Aristotle and Kant, and Kant's integration of Newtonian physics and Euclidean geometry into the fabric of his philosophy. Knowledge as a human enterprise is both dynamic and limited. It is limited because the canon of reality, like reality itself, can never be completely fathomed. It is limited because as human beings we are limited and must constantly search for knowledge. The phrase "exhaustive knowledge" is an oxymoron:

> The limitation of knowledge is certainly real, but this limitation is something derived from the intrinsic and formal nature of rational intellection, from knowing as such, since it is inquiring intellection. Only because rational intellection is formally inquiring, only because of this must one always seek more and, finding what was sought, have it become the principle of the next search. Knowledge is limited by being knowledge. *An exhaustive knowledge of the real would not be knowledge; it would be intellection of the real without necessity of knowledge.* Knowledge is only intellection in search. Not having recognized the intrinsic and formal character of rational intellection as inquiry is what led to…subsuming all truth under the truth of affirmation.[24] [Italics added]

In Zubiri's word's, reason is "measuring intellection of the real in depth".[25] There are two moments of reason to be distinguished (1) intellection in depth, e.g., electromagnetic theory is intellection in depth of color;[26] (2) its character as *measuring,* in the most general sense, akin to the notion of measure in advanced mathematics (functional analysis). For example, prior to the twentieth century, material things were assimilated to the notion of "body"; that was the *measure* of all material things. But with the development of quantum mechanics, a new conception of material things was forced upon science, one which is different from the traditional notion of "body". The canon of real things was thus enlarged, so that the measure of something is no longer necessarily that of "body". Measuring, in this sense, and the corresponding canon of reality, are both dynamic and are a key element in Zubiri's quest to avoid the problems and failures of past philosophies based on static and unchanging conceptions of reality.

Postulation and reality

Because reality is a formality, and not a zone of things, its content can be postulated. This is the primary vehicle for disciplines such as mathematics and literature. But it also is important in science since science postulates the content of reality through its theories—loosely speaking, we could say that it postulates reality. As Zubiri explains:

> In-depth reality is actualized in what has been freely constructed by postulation…It is not truth which is postulated

> but real content. And this is so whether dealing with theoretical or non-theoretical construction. It is not postulation of reality but reality in postulation. One postulates what belongs to something [*suyo*] but not the *de suyo* itself. Postulation is the mode by which in-depth reality is endowed with a freely constructed content.[27]

The great success of science over the past four centuries has been due to its use of such postulation:

> In physics, at the beginning of the modern age, there were two great free creative efforts to intellectively know rationally the in-depth reality of the universe. One consisted in the idea that the universe is a great organism whose diverse elements comprise systems by sympathy and antipathy. But this never had much success. The one which triumphed was the other conception. It was the free creation which postulates for cosmic reality a mathematical structure. That was Galileo's idea in his *New Science*: the great book of the universe, he tells us, is written in geometric language, i.e., mathematics.[28]

Due to the state of knowledge of mathematics—what we would now term "ordinary differential equations"—this view of physics became identified with a particular type of determinism known as *mechanism*, and the idea that science could be other than mechanistic in this sense was changed only after prolonged battles, fought mostly in the early decades of the 20th century. But this changed with the development of quantum mechanics, when the recognition of the probabilistic nature of physical laws was forced upon the reluctant practitioners of physics—but was understandable because of advanced in mathematics itself, which made clear that determinism was a special case of probabilistic and statistical descriptions. Thus

> The mathematical structure of the universe subsists independently of its earlier mechanistic form, which was too limiting. *Mathematicism* is not mechanism. And all of this is, without any doubt, a free creation for rationally intellectively knowing the foundation of all the cosmos. Its fertility is quite apparent. Nonetheless, the fabulous success of the idea of a mathematical universe cannot hide its character of free creation, of free postulation, which precisely by being free leaves some unsuspected aspects of nature in the dark.[29]

With the notions of canon and postulation, it is possible to construct Zubiri's vision of the scientific method.

Scientific method

Zubiri never explicitly stated his notion of the so-called "scientific method", but it is possible to deduce it from his writings, and in particular, his idea of the *canon of reality* and his notion of *postulation of reality*. Indeed, by formulating the scientific method in terms of these two ideas, matters are notably clarified. In this approach science involves 5 steps:

1. *Start with some knowledge of reality* (at all three noetic levels-primordial apprehension, logos, and reason). All science is based on observations which ultimately derive from primordial apprehension, and all rational explanations are intended to tell us about reality beyond apprehension which may account for our observations. Typically the scientist starts from knowledge at least at the logos level, and more often at the level of reason. For example, the Special Theory of Relativity starts with observations about Galilean (non-accelerated) frames, and the speed of light, and as we noted, symmetry in the form of the Lorentz transformation. All of these are already concepts at the rational level, though they clearly use the logos level because things are named. Likewise quantum mechanics starts with the observed distribution of light frequencies from atoms, and Maxwell's theory starts with observations about electric and magnetic fields. In the theory of evolu-

tion, as promulgated by Darwin, one starts with observations about similarities in physiological function and also historical sequences of organisms, the existence of random changes in genetic material, and the existence of the process of natural selection.

2. *Postulate the content of reality*. This may involve postulation of new things such as atoms or quarks, and their characteristics stemming from their essences; or it may involve postulation of new relationships among things already known, such as the Universal Gas Law. There may be a combination of the two. In the case of the Special Theory of Relativity, the reality postulated is that the speed of light is a universal constant, and that all Galilean frames are equivalent, i.e., there is no absolute space or time. Quantum mechanics postulates that energy is quantized and that the position of particles is described by a probability density function—which is equivalent to saying that they do not have absolute position and momentum. Maxwell's theory postulates a set of relationships among electric and magnetic fields, as expressed in his famous four equations. Darwin's theory postulates that random mutations operated on by natural selection can account entirely for the history of life on earth.

3. *Explore the postulated content (reality)*. At this stage the scientist explores the new content of reality which has been postulated by the tools at his disposal. Typically this involves deduction or other inference of consequences about the new reality, and possibly visits to new places, construction of new experimental equipment, or reexamination of existing materials.

4. *Verify*. At this stage the scientist seeks to determine if what has been learned through the exploration of postulated content (reality) is in accord with our experience of reality beyond apprehension. This is done by finding things in the postulated reality which have not yet been observed in reality beyond apprehension, and then searching for them in that reality, usually by experimentation. Verification in this case takes the form of congruence.

5. *Check for satisfactory result*. If the new theory works for known data, and makes successful predictions, make any necessary additions to the accepted canon of scientific reality, and continue to explore reality seeking new evidence, for or against the theory. In the case of discrepancies, gather more data, rethink postulations, and then continue through the loop until a satisfactory level of agreement exists. See Figure 6.

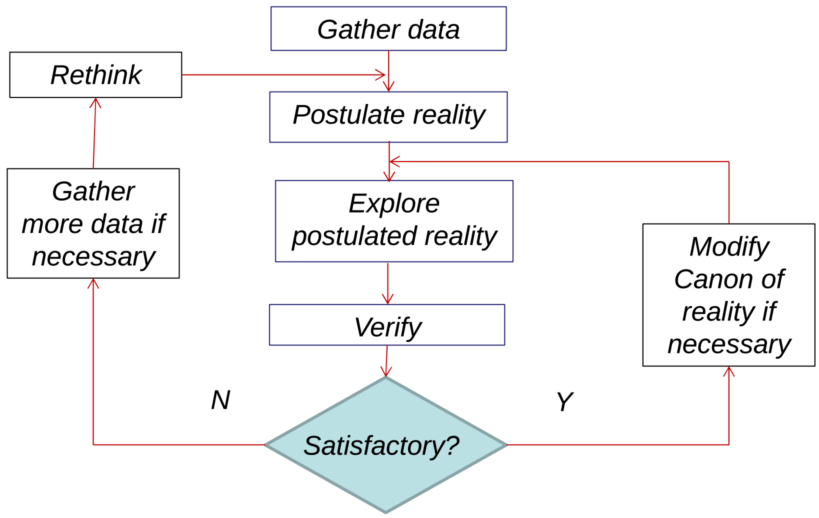

Figure 6. Scientific Method Based on Zubiri's Philosophy

For Zubiri, of course, reality is formality, and not a zone of things. Hence the realists' fundamental problem—how to establish a relationship between mathematical formulations of scientific laws and theories and the real world—is not an issue because any scientific theory itself *postulates* reality. Thus the real issue—for both science and philosophy—is not why we can describe reality with our theories, but *how well postulated reality corresponds to reality beyond apprehension.* We can describe reality with our theories because they *postulate* it. For example, phlogiston was postulated to account for observed transformations in combustion. But further research disclosed that there is no such entity—it did not correspond well with reality beyond apprehension. However the postulation of subatomic particles such as electrons, photons, and quarks has proved useful. The integration of postulated reality and apprehension is very tight in Zubiri's philosophy. This is illustrated by his famous example of photons and color: the photons are postulated reality, but there are not two realities, photons and color; rather, color is the photons as sensed:

> Now, reason or explanation is above all the intellection of the real in depth. Only as an explanation of color is there intellection of electromagnetic waves or photons. The color which gives us pause to think is what leads us to the electromagnetic wave or to the photon. If it were not for this giving us pause to think, there would be no intellection of a beyond whatsoever; there would be at most a succession of intellections "on this side".[30]

5. Modify the canon of reality. Successful theories remain as beyond-reality-postulations and the reality they postulate usually enlarges our canon of reality; unsuccessful theories become essentially literary postulations; indeed, "science fiction" as a literary genre is closely related to failed scientific theories. Thus the Theory of Relativity gave us relative space and time, and the speed of light as a universal constant, as well as the equivalence of mass and energy, made famous by $E = mc^2$ and of course nuclear weapons.

Note that steps (3) and (4) do not require experiments such as those typically done in chemistry and physics; it is only necessary for the theory to tell the scientist to look where he has not looked before, to find something that he has not found before. Otherwise sciences such as cosmology and geology, for example, could not exist, since we cannot make stars in a laboratory, or even travel to them. Nor can we recreate mountain-building plate tectonics.

Revisions to Zubiri's Philosophy of Science and Philosophy of Reality

It is with respect to postulation of reality that the new view of physics has led us to a more profound understanding. Rather than postulate a new descriptive law, such as the Universal Gas Law or Schrodinger's equation, the physicist starts with some basic observations and a symmetry principle, and infers the descriptive law. For example, consider the hydrogen atom:

> …the rotational symmetry group imposes the shapes that a hydrogen atom can assume, and…the energies associated with these structures are accurately reflected in the hydrogen spectrum.[31]

Now there are many symmetries possible, often expressed in terms of symmetry groups, such as SO(2), the group of rotations about a point in two dimensions; or SO(3), the group of rotations about the origin in three dimensions, etc. So utilizing the Myth of the Cave from Plato, the task of the physicist is metaphorically, to ascend from the cave of day-to-day experience in which he sees but the shadows of ultimate reality on the wall, to the light of day of reality, to wit, the symmetries which govern reality, though mathematics. Zee Notes:

> The discovery of a symmetry is much more than the discovery of a specific phenomenon. A symmetry of spacetime, such as rotational invariance or Lorentz invariance, controls all of physics…Lorentz invariance, born of electromagnetism, proceeds to revolutionize mechanics. And once the laws of motion of particles are revised, our conception of gravity has to be changed as well, since gravity moves particles.[32]

What is most interesting is that all these symmetries have already been discovered and analyzed by mathematicians; so what Zee is referring to here is not the discovery *per se*, but the discovery of applicability. Thus physicists are not in the business of discovering new symmetries, but rather with determining in which symmetries physical reality "participates", so to speak. With respect to mathematics, Zubiri notes:

> A free thing is the physical reality with a freely postulated content. Such are the objects of mathematics, for they are real objects constituted in the physical moment of "the" reality in a field, the same reality according to which things like this stone are real. The *moment* of reality is identical in both cases; what is not the same is their *content* and their *mode* of reality. The stone has reality in and by itself, whereas the circle has reality only by postulation. Nonetheless the moment of reality is identical.[33]

So in this sense we have mathematical realities *determining*, not *describing*, reality. In this way, the boundary between mathematics and physics—long thought to be unbridgeable—has now broken down. The postulation step in science, or at least in fundamental physics, is postulation of a symmetry—something already real, from mathematics—from which implications about reality beyond apprehension are drawn, rather than a direct postulation of reality beyond apprehension. This is the sense in which Zubiri's philosophy of reality must be modified.

What is the reality of symmetry? Symmetry, known and studied by mathematicians since the 19th century, is real in the same sense as other mathematical objects—spaces, irrational numbers, etc. But not every symmetry governs reality. So those symmetries that have been found to "dictate" reality—in the form of fixing particle number, types, and characteristics—have a special type of reality which goes beyond that of pure mathematical objects, but is not that of directly observable entities such as bodies or even waves. It does not seem that Zubiri anticipated this blurring of the distinction between mathematics and science, though it most likely would have delighted and intrigued him, especially in view of his theory of the reality of mathematical objects and the recognition of reality as formality rather than a zone of things.

In a famous essay, Nobelist Eugene Wigner asked why mathematics is so effective in describing reality through science.[34] While it is obviously impossible to give a non-theological answer to this question, Zubiri's philosophy at least gives some insight. The fact that mathematicians postulate *reality*, and postulate many *types* of reality, with widely varying structurality, suggests that some of these postulations might have applicability to our experience of reality. Kant's explanation of this applicability—that the mind synthesizes reality according to rational principles such as Newtonian mechanics—is clearly wrong. Zubiri's idea, applied to symmetry, seems much closer to the truth. Although symmetry is a notion that comes from ordinary experience, its applicability in fundamental physics stems from extensive work (i.e., postulation) on the part of mathematicians of such things as symmetry groups. The symmetries that appear to govern reality stem from postulation first as reality by mathematicians, then postulation as reality in some sense by physicists describing the world.

How far the use of symmetry will take us, that is, the extent to which reality "participates" in symmetry, is unclear. Attempts to unify the four forces of nature based on ever larger symmetry groups appear to have stalled, at least in the sense that "supersymmetry" and string theory are not yielding any verifiable predictions. In QFT, forces are interpreted as interactions with gauge bosons, as noted earlier; but gravity has stubbornly resisted this interpretation.

As for the scientific method, the postulation step is where a small correction must be made. As noted, the scientist postulates not a law describing reality beyond apprehension, but a symmetry of nature. And he only postulates the applicability of an already known symmetry. Then he proceeds to deduce the consequences and see how well the fit observations.

Because of its belief in reality as a zone of things, the situation we now have in physics, with virtual particles, symmetry, and gauge fields, matters are very dire for the empirical tradition in philosophy, capped by Hume, for whom knowledge was divided into matters of fact and relations of ideas. The rather stark overlap of "ideas", i.e. mathematics, and "fact", i.e., physical reality, makes his philosophy and that of the other empiricists untenable. In a related vein, the general Kantian approach is also untenable. Kant accepted by and large Hume's criticisms, but sought to overcome them by building causality and physics as then understood into his philosophy. The idea that "categories" can change and expand (essentially Zubiri's canon of reality) was not really amenable to Kant's philosophy; and the idea that mathematical notions such as symmetry can exercise a power over reality does not fit either, since Kant envisioned the domination of mind over matter as a type of synthesis of raw experience by the mind, not something that the mind can truly grasp of reality. The situation for the rationalist philosophies is somewhat better, but their lack of basis in empiricism is still ultimately fatal.

Zubiri's comments still hold true by and large:

> In summary, that which specifies intellection, making of it knowledge, is in-depth reality. And this in-depth reality does not consist in either objective ground (Kant), or in intelligible entity (Plato), or in causality, still less in necessary causality (Aristotle), or in the absolute (Hegel). In-depthness is the mere "beyond" as "ground-reality" in all the multiple modes and forms which this beyond can assume. Causality or the principles of a deductive form of knowledge are not thereby excluded,

nor are the possible steps toward an absolute reality. What is excluded is the idea that something of sort formally constitutes the in-depth reality in which reason is installed by the movement of intellection as thrown from from the field to the beyond.[35]

Conclusion

Zubiri's philosophy of scientific reality is able to absorb the new developments in QFT, as is the scientific method implied by his philosophy. In particular, the new modes of reality, represented by gauge fields, virtual particles, and symmetry groups, fit quite well with his thinking that the canon of reality is never fixed, and can be expanded. The new modes of reality do not have to be identified with "bodies" in any classical sense. Nor is it the case that we are compelled to think about reality in these ways, as Kant believed. We have discovered these new forms of reality in the course of normal scientific investigation, and they have replaced earlier notions.

Notes

[1] The text of this article will appear in a revised from in a forthcoming book on Zubiri's theology, co-written by several Zubiri scholars.

[2] Xavier Zubiri, *Inteligencia y Razón* (Madrid: Alianza Editorial/Sociedad de Estudios y Publicaciones, 1983), 57.

[3] *Ibid.*, p. 56-57; English edition, p. 261.

[4] Leonard Susskind and George Hrabovsky, *The Theoretical Minimum*, New York: Basic Books, 2013, p. 195.

[5] Chris Quigg, *Gauge Theories of the Strong, Weak, and Electromagnetic Interactions*, Redwood City: California, Addison-Wesley, 1983, p. 43-44.

[6] Susskind and Hrabovsky, *op. cit.*, p. 211.

[7] IRE, p. 207; English edition, p. 75.

[8] Xavier Zubiri, *Inteligencia y realidad* (IRE), p. 104-105; English edition, *Sentient Intelligence,* tr. by Thomas Fowler, Washington, DC: Xavier Zubiri Foundation of North America, 1999, p. 40.

[9] IRA, p. 57; English edition, p. 261.

[10] Robert Klauber, *Student Friendly Quantum Field Theory,* p. 340, 352.

[11] *Ibid.*, p. 307.

[12] Anthony Zee, *Fearful Symmetry,* Princeton: Princeton University Press, 2007, p. 159-160.

[13] Vincent Icke, *The Force of Symmetry*, Cambridge: Cambridge University Press, 1995, p. 103.

[14] After Anthony Zee, *Fearful Symmetry*, Princeton: Princeton University Press, 2007, p. 96.

[15] *Ibid.*

[16] *Ibid.*, p. 97.

[17] *Ibid.*, p. 96.

[18] Zee, p. 160.

[19] Zee, p. 73.

[20] IRA, p. 310; English edition, p. 352.

[21] IRA, p. 57; English edition, p. 261.

[22] IRA, p. 310-311; English edition, p. 352.

[23] Zubiri, *Sentient Intelligence*, op. cit., p. 261; *Inteligencia y razon*, p. 57.

[24] Zubiri, *Inteligencia y razón,* p. 261-262; *Sentient Intelligence*, p. 336.

[25] Zubiri, *Inteligencia y razón,* p. 45; *Sentient Intelligence*, p. 257.

[26] Zubiri, *Inteligencia y razón,* p. 43; *Sentient Intelligence*, p. 256-257.

[27] IRA, p. 129-30; English edition, p. 285.

[28] IRA, p. 132; English edition, p. 286.

[29] IRA, p. 132; English edition, p. 286.

[30] IRA, p. 43; English edition, p. 256-257.

[31] Vincent Icke, *The Force of Symmetry*, p. 102.

[32] Zee, p. 73-74.

[33] Zubiri, *Inteligencia y logos*, p. 134; English edition, p. 153.

[34] Eugene Wigner, "The Unreasonable Effectiveness of Mathematics in the Natural Sciences", *Communications in Pure and Applied Mathematics*, vol. 13, No. 1 (February, 1960). Reprinted in *The World of Physics,* Vol. 3*,* ed. by Jefferson Hane Weaver, New York: Simon & Schuster, 1987, pp. 82-96.

[35] IRA, p. 168-169; English edition, p. 302.