

Transubstantiation*

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Abstract

Normal matter consists of atomic nuclei, electrons and photons. Volumetrically the photons predominate. Photons are quantized light. Human reason has formulated the physical laws obeyed by quantized light. The mathematical formulation requires vector spaces with infinitely many dimensions. Therefore the reality of wine and bread in modern physics is truly transcendental and abstract. The abstractness of the physical reality of normal matter challenges simple minded agnosticism. It permits all

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faithful Christians to paraphrase transubstantiation as a mysterious transition from visible and natural light to invisible and supernatural (divine) light.

Zusammenfassung

Normale Materie besteht aus Atomkernen, Elektronen und Photonen. Volumetrisch überwiegen dabei Photonen. Photonen sind quantisiertes Licht. Die menschliche Vernunft hat physikalische Gesetze formuliert, denen quantisiertes Licht gehorcht. Die mathematische Formulierung erfordert unendlichdimensionale Vektorräume. Insofern ist die Wirklichkeit von Wein und Brot in der modernen Physik transzendent und abstrakt. Diese Abstraktheit der physikalischen Wirklichkeit normaler Materie erlaubt es jedem Christgläubigen anzunehmen, daß in der Transsubstantiation ein geheimnisvoller Übergang von sichtbarem natürlichen Licht zu unsichtbarem übernatürlichen (göttlichen) Licht stattfindet.

1 Problem Statement

All deniers of eucharistic transubstantiation deny that the words spoken by the priest *“in persona Christi”* change anything real in wine or host. Deniers, who claim to believe in Christ, however, must be asked: How do you know?

Modern theologians tend to shift the immaterial events from the supernatural level of essence-change to the natural level of signification-change when they speak of *“transignification”* and opine, that during transubstantiation the eucharistic species change merely their significations. Also some advocates of orthodoxy [7] appear to struggle with the reality of transubstantiation when they view reality from a personalistic perspective as an¹ *“in itself*

¹ *“in sich geeintes Selbstverhältnis, das im Personsein zum Ausdruck kommt,”*

unified self-relation, that is expressed in person-being,” [7, S. 641], i.e. as reality² *“of an essentially different kind”* [9, S.347]. In a recently published article [12] it is suggested to replace the concept of transubstantiation with *“substantiation”*. Of course, Spaemann does not deny the supernaturalness of eucharistic transubstantiation, but he sees an erroneous philosophical assumption or hypothesis in the word transubstantiation. Rightly viewed, bread is not a substance, he opines, at least not a primary substance such as e.g. a living being. Explicitly Spaemann writes³, that *“there is no bread-substance, that could be transformed into the substance of Christ’s body, no process, that we could call transubstantiation”*. Mixtures such a bread are philosophically speaking only artefacts, and have, according to Spaemann, no independent being, no⁴ *“self-stand”*, no⁵ *“self-being”*, that goes beyond their⁶ *“significance for the world of humans”*.

Disputing the substance of bread [12], just as personalizing reality [7, 11], contradicts the dogmatic formulations in [10, Cap.IV and Can.II]. Effectively this raises once again the question whether, what the Catholic Church continues to put forward to believe and to teach since October 11th, 1551, is still worthy of belief and teaching in the face of modern physics. In modern physics wine and host are material substances, composed hierarchically from light (photons) and massive particles (electrons, protons, etc.) to form atoms, molecules and bulk matter (*“substantiae compositae”*), that obey true and God given laws of physics. († תְּמַחַת הַיְיָ אֱלֹהֵינוּ *“et lex tua veritas”* Ps 118:142).

² *“von wesentlicher anderer Art”*

³ *“Es gibt keine Brotschubstanz, die in die Schubstanz des Leibes Christi gewandelt werden könnten, und keinen Vorgang, den wir Transsubstantiation nennen könnten”*

⁴ *“Selbststand”*

⁵ *“Selbstsein”*

⁶ *“Bedeutsamkeit für die Menschenwelt”*

Given that Spaemann disputes the substance of bread, it is remarkable that he acknowledges explicitly the substance of chemical compounds, writing in⁷ [12, S.200] : “*Contrary to chemical compounds, that form new substances, bread is only a mixture of ingredients, that do not ask to be mixed*”. Let us stress therefore, that the primary accidents of bread (crumb, melanoidines etc.) and wine (bouquet, alcohol etc.), by which we identify them as bread and wine, are not produced by mechanical mixing, but by chemical reactions. Of course, bread production starts with mixing flour, water, salt, yeast and lactobacili mechanically, but this mixing does not yield bread, just as squeezing grapes does not yield wine but mash. Reactions of multiple chemical components, that are still only partially known, are crucial for producing wine and bread. In the case of bread the mixing of flour and water creates gluten networks via chemical reactions (e.g. disulphide bridges are formed between the sulphur atoms of two cysteines) whose macroscopic effect is the transition from powder and fluid to dough. Also during the baking of dough numerous chemical reactions produce gases, hydrolize or pyrolize carbohydrates, or generate flavours (Maillard reaction). Mash, flour, dough, bread and wine are chemical compounds and as such they are just as artificial or natural as plexiglass or minerals.

This article originated from a discussion with Robert Spaemann and the problem statement is a result of Spaemann’s suggestion to delete the prepositional prefix *trans* [12] although the Council of Trent [10, Sessio XIII. Celebrata die 11. Mensis Octobr. 1551, Decretum de Sanctissime Eucharistiae Sacramento, Cap.IV und Can. II] following Saint Thomas Aquinas⁸ insisted

⁷ “*Im Unterschied zu chemischen Verbindungen, durch die neue Substanzen entstehen, ist Brot nur eine Mischung von Ingredienzien, die nicht danach verlangen, gemischt zu werden*”.

⁸ “... *haec conversio proprie transsubstantiatio vocatur.*” (in: Tertia Pars Summae Theologiae, Quaestio LXXV, Articulus VIII)

on the complete word transubstantiation when it declared:

... idque nunc denuo sancta haec Synodus declarat, per consecrationem panis & vini, conversionem fieri totius substantiae panis in substantiam corporis Christi Domini nostri, & totius substantiae vini in substantiae sanguinis eius: quae conversio convenienter, & proprie a Sancta Catholica Ecclesia Transubstantiatio est appellata.

This raises the question what the Council of Trent meant with the word substance. Concurrently, this raises the question what the reality of bread and wine is prior to their conversion and whether this reality is not so much a⁹ “*being-in-and-of-itself*” but a¹⁰ “*being-for-us*” as it is nowadays often taught [7]. This poses also the problem of the reality of the real presence of Our Lord in space and time (cf. [9, p. 347]). This article thus deals with three questions:

- (i) What is meant by the substance of bread and wine?
- (ii) What is the reality of bread and wine?
- (iii) When and where does the Real Presence in the Eucharist begin and end?

The answers (in Section 5) show how the truth of physics might facilitate the consent of reason to the dogma of transubstantiation, instead of rendering such consent more difficult.

⁹ “*An-Sich-Sein*”

¹⁰ “*Für-Uns-Sein*”

2 Substance

If bread does not have substance, then what does it mean to have substance? The concept of substance in the Council of Trent was¹¹ *“introduced into the discussion to formulate a non-naturalistic realism and to end the absurd position of the antiberengarian »orthodoxy«.* After all, substance was a metaphysical concept which was “per definitionem” not quantitative. The question that arose –and still arises– is: What, properly speaking, is “reality?” Whichever answer one may give to this question of questions, the classic teaching on the Eucharist was convinced that “reality” and “quantity” do not coincide, and that the eucharistic reality is not to be found on the quantitative (thence not on the chemical, anatomical and so on) level, but that it is reality of an essentially different kind, but still “reality” [9, S. 347]. Superficial polemics would thus be refuted, were it not for the fact that, for material entities, the concept of substance has evolved from a metaphysical-philosophical concept into a physico-chemical concept¹².

¹¹ *“in die Diskussion gebracht, um einen Realismus zu formulieren, der nicht naturalistisch war, und um die absurde Position der antiberengarischen »Orthodoxie« zu beenden. Denn Substanz war ein metaphysischer Begriff, von dem “per definitionem” feststand, daß er nicht auf der Ebene des Quantitativen liege. Die Frage, die hier also aufstand und aufsteht, lautet: Was ist das eigentlich: “Wirklichkeit, Realität?” Wie immer man auf diese Letztfrage antworten mag, die klassische Eucharistielehre war davon überzeugt, daß “Realität” und “Quantität” nicht ineinanderfallen und daß die eucharistische Realität nicht auf der quantitativen (also auch nicht auf der chemischen, anatomischen und so weiter) Ebene liegt, sondern Realität von wesentlich anderer Art, aber eben doch “Realität” ist.”*

¹² A quantitative concept of substance has entered also into business science, where one speaks of the substance of a corporation.

2.1 Physics

The concept of substance in physics, chemistry and natural philosophy is anchored, even legally, in the International System of Units (SI-system). The SI-unit mol quantifies the “*amount of substance*” or the “*quantità di sostanza*”, at least in English and Italian. In French one speaks of “*quantité de matière*”, i.e. of matter instead of substance, and in German of “*Stoffmenge*”, i.e. of ύλη instead of substance.

Definition 1 (Substance in physics and chemistry) :

Substance in physics and chemistry denotes pure or mixed materials out of which material things are composed.

Pure materials are obtained from natural materials by separation and purification processes such as filtration sedimentation, flotation, chromatography, centrifuging, precipitation, recrystallization, and many more. Mixed materials (mixtures) differ from pure materials in that the weight ratio of their components can be arbitrary. For pure materials the weight ratio of their ingredients is stoichiometrically fixed¹³.

Pure water consists stoichiometrically of two parts hydrogen and one part oxygen. Pure wine, however, is a mixture of hundreds of components, with varying fractions. They include water, ethyl alcohol, glycerol, acids, such as tartaric, citric, lactic, malic or carbonic acid, trace elements, such as calcium, potassium, sodium or magnesium, colors, aroma, flavours, dyes and more.

Chemically pure materials correspond to chemical formulas. They can be decomposed chemically into other pure materials. Finally one obtains the most basic chemically pure substances, called chemical elements. They are systematized in the periodic table of chemical elements.

¹³Stoichiometry means measuring the στοιχεῖα, i.e. the basic ingredients, ultimate constituents or elements.

Accidents¹⁴ of chemical substances are often described by density fields. Examples are mass densities, energy densities, charge densities or concentrations. The density fields fulfill mathematically formulated laws of physics and chemistry. Mathematically, density fields are real-valued functions on subsets of space and time. The subset on which a density field is non-zero is called its support in mathematics. The semantic consistency of physics allows one to relate the density fields of chemical physics with density fields in molecular or atomic physics. These in turn are related with densities in nuclear physics, the densities in nuclear physics with those in elementary particle physics and so on. During this progression the support of mass and charge densities shrinks into tiny pointlike regions.

In this way the support of normal massive matter dissolves into the ever smaller. What remains are electromagnetic fields that fill space. Electromagnetic waves with wavelengths between 400 and 800 nanometers are visible to the human eye. They are called visible light. Therefore chemical substances are exactly the same substance as light, if one neglects tiny mass points¹⁵.

2.2 Metaphysics

In Aristotelian metaphysics materials are substances, but the paradigmata for substance are not hydrogen, oxygen or light, but living creatures (such as humans, mice or microbes). For higher

¹⁴in the sense of “*accidentēs*” (lat.) meaning roughly “properties”

¹⁵The ontological signification of physical fields can therewith remain open. In tropical ontology electrons would be property bundles. Within ontic structural realism they would be representations of symmetry groups. This ontological problem corresponds to wave-particle duality. Physicists regard electromagnetic fields also as photonic matter (photon gases) and investigate exotic matter consisting of ontologically rather questionable quasi-particles such as phonons, magnons, polarons or excitons.

creatures there exist individuals of one and the same species that manifest and express themselves as individuals in their appearance and their activity. Thereby the substance of higher creatures is identified as that which brings these observable properties (accidents) into being¹⁶.

In metaphysics and philosophy substance is something that has being (existence) in itself (*per se*), and that carries observable properties (accidents). Spaemann defines substance somewhat more restrictively:

Definition 2 (Substance according to Spaemann) :

*The substance of a thing is that self-being essential core of a thing, that implies an own dynamical composedness, an own teleological structure due to which something is at stake for natural things, namely first and foremost its own self-assertion*¹⁷ [12, S.200].

The terms “*essential core*”¹⁸ (as opposed to essence), “*dynamical composedness*”¹⁹, “*teleological structure*”²⁰, or “*Self*”²¹ are not explained in [12]. Instead it is stated: “*For a horse something is at stake. It is somehow to be a horse. It is not somehow to be a car. For a car nothing is at stake.*”²² In other words: Only living

¹⁶Individuals of lower creatures (e.g. microbes) are often an integral part of higher creatures. For example, it is estimated that a human has more microbes (enterobacteria) than body cells (doi:10.1371/journal.pbio.1002533).

¹⁷“*Die Substanz eines Dinges ist der selbstseiende Wesenskern eines Dinges, der eine eigene dynamische Verfasstheit impliziert, eine eigene teleologische Struktur, aufgrund derer es natürlichen Dingen um etwas geht, und zwar zuerst und vor allem um ihre eigene Selbstbehauptung.*”

¹⁸“*Wesenskern*”

¹⁹“*dynamische Verfasstheit*”

²⁰“*teleologische Struktur*”

²¹“*Selbst*”

²²“*Einem Pferd geht es um etwas. Es ist irgendwie ein Pferd zu sein. Es ist nicht irgendwie ein Auto zu sein. Einem Auto geht es um nichts.*”

creatures have substance according to Spaemann.

For tiny creatures (microbes) the distinction between different individuals of one and the same species is more difficult, if only, because a microscope is needed. Without a microscope it is also impossible to distinguish objects of identical appearance and shape (such as crystals or cars). On the other hand two identical cars are distinguishable, even under identical usage, by their service life. This results from production tolerances and microscopic details of its parts (such as granularity, texture etc). Individual differences between two breads or hosts manifest themselves in their different pore structure. Inanimate things and artefacts also exhibit “*dynamical composedness*” insofar as their atoms fluctuate thermally at nonzero temperatures. They exhibit a “*teleological structure*” insofar as these dynamical fluctuations tend towards local equilibrium.

According to Spaemann the (improper) substance of artefacts is determined by their purpose resp. signification. Artefacts are, apart from their purposiveness, nothing beyond their properties. And that is what Spaemann says: “*Bread is defined by a list of properties. It is nothing beyond these properties*”²³[12, S.200]. “*In other words: Bread is not a substance. True, there is an “essence” of bread, but this essence exists only within the human world, the world of “signification”. It is, what it signifies in this world. It does not have being outside of it. ... If, however, humanity were to vanish from this planet, then also the human world, the world of signification, would vanish. Then, bread would no longer be bread.*”²⁴[12, S.201].

²³ “*Brot ist definiert durch eine Reihe von Eigenschaften. Es ist nichts jenseits dieser Eigenschaften.*”[12, S.200].

²⁴ “*Mit anderen Worten: Brot ist keine Substanz. Wohl gibt es ein “Wesen” des Brotes, aber dieses Wesen existiert nur innerhalb der menschlichen Welt, der Welt von “Bedeutung”. Was es innerhalb dieser Welt bedeutet, das ist es. Es hat kein Sein außerhalb derselben. ... Wenn allerdings die*

Similarly it is claimed in [7, S.591] that bread and wine have their *“life supporting signification not first from their being-in-themselves before God, but from their “being-for-us”.* *“That is, the objectivity of their signification is not guaranteed by a Godly act of creation, but rather by a common social act of construction or ... by agreement of a community of speakers through and for the humans of this community.”*²⁵ [7, S.592].

The conception of reality, that expresses itself in such sentences, contradicts everyday understanding. It contradicts also Aristotle and the philosophy of *“double substantiality of creatureal being”*²⁶, which grants artefacts despite their *“being-from-somewhere-else a being-in-self-standing”*²⁷ [8, S.151]. Whoever has fed pigeons with bread, or whoever has outdoors protected his bread from discovery by grizzly bears, is somehow convinced that bread remains bread even without humanity. Something analogous holds for artefacts. Bridges or landmines mean something for elephants too. Even an oven that was produced by inanimate machines on an automatized production line warms not only humans in the winter, but also dead stones. Archeological artefacts remain what they have always been: drinking cups, jewellery, tax lists or temples. And that is independent of whether there still exists a human, who can read or knows their signification.

Menschheit von diesem Planeten verschwunden wäre, dann wäre auch die Menschenwelt, die Welt der Bedeutungen, verschwunden. Dann wäre Brot nicht mehr Brot.”[12, S.201].

²⁵ *“lebenserhaltende Bedeutung nicht zuerst aus ihrem An-sich-Sein vor Gott, sondern aus ihrem von Menschen in einem geschichtlichen kulturellen Kontext erwirkten “Für-uns-Sein”.* *„Das heißt, die Objektivität ihrer Bedeutung ist nicht verbürgt durch einen göttlichen Schöpfungsakt als vielmehr durch einen gemeinsamen gesellschaftlichen Akt der Konstruktion oder ... durch Übereinkunft einer Sprechergemeinschaft durch und für den Menschen dieser Gemeinschaft.“* ([7, S.592])

²⁶ *“doppelten Substantialität des geschöpflichen Seins”*

²⁷ *“Sein-von-woanders-her doch Sein-in-Selbständigkeit”*

On the other hand reality is indeed abstract, because it is created by the word of God. The λόγος creating reality is not only claimed in Jhn 1:1 und Jhn 1:3 [5] where it says Ἐν ἀρχῇ ἦν ὁ λόγος, καὶ ὁ λόγος ἦν πρὸς τὸν θεόν, καὶ θεὸς ἦν ὁ λόγος.²⁸ and πάντα διὰ αὐτοῦ ἐγένετο, καὶ χωρὶς αὐτοῦ ἐγένετο οὐδὲ ἓν.²⁹ Also in modern physics reality is characterized by a peculiar mathematical-logical abstractness. But this abstractness is not a sociological or social “*act of construction*” or the “*agreement of a community of speakers through and for the humans of this community.*” Instead this peculiar abstract reality of quantum electrodynamics resembles that ontic linkage that God Himself establishes in Jhn 8:12 when He says ἐγὼ εἰμι τὸ φῶς τοῦ κόσμου³⁰ or in Jhn 1:9: Ἦν τὸ φῶς τὸ ἀληθινόν, ὃ φωτίζει πάντα ἄνθρωπον³¹ and ἐν τῷ κόσμῳ ἦν, καὶ ὁ κόσμος δι αὐτοῦ ἐγένετο³² (Jhn 1:10).

Before the peculiar abstractness of physical reality is identified as non-commutativity and examined more closely, it is necessary to recall the concept of substance of St. Thomas Aquinas as that scholastic point of reference, that underlies the dogmatic formulation.

In *De ente et essentia* St. Thomas distinguishes between real beings and abstract (logical or mathematical) beings. Real beings are things to which the ten aristotelian categories (κατηγορεῖν means to utter, to accuse, to state) are applicable, namely substance (οὐσία), quantity (ποσὸν), quality (ποιόν), relation (πρὸς τι), location (ποῦ), time (ποτὲ), to lie (κεῖσθαι), to have (ἔχειν), to do (ποιεῖν), und to suffer (πάσχειν). St. Thomas then juxtapo-

²⁸In the beginning was the Word, and the Word was with God, and the Word was God

²⁹All things were made by him; and without him was not any thing made that was made.

³⁰I am the light of the world

³¹That was the true Light, which lighteth every man

³²and the world was made by him

ses the first category (οὐσία, *substantia*) against the other nine categories that he calls “*accidentēs*”. Insofar he defines substance as the first category of anything real.

Definition 3 (Substance according to St. Thomas Aquinas) :
Substance is that, which is by itself (“ens per se”), perseveres by itself, which subsists and exists without carrier (“ens in se subsistens”). “Ratio substantiae est per se existere” [2, a.3, arg. 4].

Definition 4 (Accidents according to St. Thomas Aquinas) :
Accident signifies a dependent being requiring another being that acts as a carrier. Accident is an “esse in alio ut in subiecto”, and thus an “ens entis”.

“*Substantia prima*” is that concrete individual essence, that is then further determined by accidents and cannot be said of anything else. “*Substantia secunda*” is the general essence obtained by abstraction from individuals and encapsulated in a general term. Concerning the connection between essence and substance Thomas states “*Essentia proprie et vere est in substantiis, sed in accidentibus est quomodo et secundum quid.*” and “*Substantiarum vero quaedam sunt simplices et quaedam sunt compositae, et in utriusque est essentia; sed in simplicibus veriori et nobiliori modo.*”

According to St. Thomas the essence of a thing lies as much “in” its substance as in its accidents. Following Aristotle, St. Thomas does not seem to argue against applying the term substance to inanimate beings such as bread or artefacts. Instead he seems to use the words essence, substance and nature synonymously when he says “*Essentia etiam alio nomine natura dicitur*” [1, Cap. I]. Let us then leave the philosophical term substance aside for a moment, and let us see how the physical reality of wine

and bread has in the course of history dissolved into the peculiar mathematical abstractness of modern physics.

3 Reality

Real is what acts. Action together with Re-Action, i.e. the mutual influence of things on each other, is called Inter-Action. Experience of reality arises from interaction when one of the interacting things stores the result (i.e. the effect). The storing part can be a living thing or a dead apparatus. A measurement apparatus in this sense is a thing that stores permanently, or documents, the effect of an interaction. In this way an interaction generates an observation, a document or a measurement. Observations, measurements and documents are the basis of experience. Experience here means: to learn for the future from the past.

3.1 Fine grained structure of matter

What is the reality of wine and bread? From what has been said the reality and essence of things emerge from observation of accidents through interaction with other things. The accidents of wine and bread, that are accessible, depend upon the type and kind of interaction, such as touching, smelling, tasting or viewing them with light. With increasing refinement of the five senses through tweezers, testtubes, magnifiers or electron microscopes also the accidents of the constituents of wine and bread became observable ever more precisely, and, as already indicated, a fine grained structure of the reality of wine and bread was discovered³³.

³³Perhaps one should say “*re-discovered*”, because the fine-grained structure of all matter has been known as אָפֶר (‘aphar) in the Old Testament (Gen 2,7, Gen 3,19 etc.).

All chemical observations pertaining to wine and bread can be successfully ordered and interpreted with the help of the atomic hypothesis. According to this hypothesis they result from interactions of tiny indivisible points of matter (atoms) that exist in empty space. The reality of empty space (vacuum) was long disputed, but finally proven with the help of technical pumps. Based on these observations atoms were viewed as the ultimate beings, as the unchangeable building blocks of reality. In this view the observable accidents of material things arise only afterwards from the complicated motions and interactions of countless atoms.

Towards the end of the 19th century the radioactive decay of atoms was discovered. Thereby the atoms lost their fundamental significance as the ultimate, indivisible and unchangeable building blocks of matter. They turned out to be changeable and composite. Three constituents were found: protons, neutrons and electrons, of which protons and electrons are stable in free space, while neutrons are unstable in free space, but stable inside the atomic nucleus. The substantial granular reality of atoms became the accidental reality of even more strongly localized atomic nuclei and elementary particles.

3.2 Light and reality

Around the time radioactivity was discovered the refined scrutiny of electric and magnetic interactions showed that the forces within and between atoms arise from fluctuations of electromagnetic fields. The proper reality and action of atoms results not so much from the tiny grains of mass, but from the electromagnetic force fields filling the space between them. Unfortunately the idea of force fields without a carrier substance to carry or mediate the forces is much less intuitive than the idea of particles moved by forces, that act at a distance.

To avoid the non-intuitive abstractness of fields without a car-

rier some kind of a material ether (the fifth element of Aristotle) was long assumed to fill the vacuum. The ether was supposed to carry electromagnetic force fields exactly as an elastic body carries mechanical stress fields when it is deformed. Despite an intensive search for the reality of the ether no action, reaction or interaction of the ether with other things has been found to date. The ether hypothesis is therefore held to be physically disproved.

Instead of the ether, the electromagnetic field in vacuum was confirmed as the proper reality, the proper being of things. The reality of fields is found in their observable accidents such as waves, oscillations and fluctuations. These waves and oscillations can be directly seen and measured with the help of test charges, but they do not have a material carrier, i.e. they are not oscillations “*of something*”. Sound waves are oscillations of air, surface waves on a pond are oscillations of water. But for electromagnetic waves, such as light, nothing oscillates. Also for matter waves, such as electrons, nothing oscillates. Such waves exist in vacuum, in empty space. Their wave lengths (i.e. the distance between maxima and minima) can have any value between zero and infinity. Electromagnetic waves in empty space with wave lengths between four hundred and eight hundred nanometers are perceived as visible light by the human eye. To paraphrase: the reality of bread and wine is largely the reality of natural, but mostly invisible light³⁴. Although invisible light carries observable accidents, it has itself no material carrier.

³⁴The capital importance of light in physics was again anticipated in holy scripture. Not only the plain text of Gen1:1 but also the hebrew word אור (’owr) for light bear witness. The three letter word אור links the letter א (aleph) to the letter ר (resh) using the hook ו(w), meaning ’and’, as a link. The letter א (aleph) stands for head of a bull. It is the very first in the hebrew alphabet and אלהי (aluph) means sovereign or “*princeps*”. The letter ר (resh) means head of a man, so that the hebrew word אור for light in its very letters signifies ’head and head’, i.e. something that is truly first.

The ontological identity of visible and invisible light is evident from modern imaging techniques, such as night vision devices, thermal imaging, medical imaging or hard X-ray imaging at airport security checks. Waves of invisible light with wavelengths around 10 centimeters are used in microwave ovens to heat food. Longer wavelengths are used in television or radio communications. Electromagnetic waves fill the vacuum between atoms and within atoms. Note also that light rays in vacuum define lightcones, and lightcones define the concept of simultaneity in space-time. A lightcone is the set of events that is simultaneous with the event at its apex.

It is important to point out that the physical vacuum is not simply “*nothing*” in the sense of non-existing or not-being. Vacuum is defined as the groundstate of a spatial region without atoms or other particles. Groundstate means the state of lowest energy. At present it is unclear whether this definition is physically reasonable and mathematically free from contradictions.

The non-intuitive abstractness of light waves without a material carrier is somewhat alleviated by the fact that the electromagnetic field has its cause and origin in the elementary particles whose motions it causes and determines. Electrons and protons are the sources (מַעֲיָן, *mayan*) of electromagnetic fields (fluxes). With this in mind the elementary particles would again be the primary reality and the empty space between them would only have a limited degree of reality inasmuch as it provides the stage for force fields and geometry. But this hope to salvage an intuitive conception of reality is abruptly ended by the physical facts.

3.3 Commutativity

When bread and wine are observed under high magnification something peculiar happens: Certain combinations of observable

accidents can no longer be ascertained or measured simultaneously. The accidents elude observation. A perspicuous explanation for this fact is not known.

The clearest and most general formulation of the observations is non-commutativity. To illustrate it consider the accidents of location x (locus, $\pi\omicron\upsilon$) and time t (tempus, $\pi\acute{o}\tau\epsilon$) of a small drop of wine with a mass $m = 1\text{g}$ of one gram. Let $x(t)$ denote its (center of mass) position at time t and let v denote its velocity. The velocity is defined as the change of position $x(t_2) - x(t_1)$ during the time interval between instant t_1 and t_2 with $t_1 < t_2$ divided by the duration $t_2 - t_1$ when it is small, i.e. when t_2 approaches t_1 . One of the most important general laws of nature states that the product xv is not the same as the product vx , although this law of nature was not noticed for many centuries. Position and velocity of the drop of wine are strictly speaking not commutative.

A quantitative measure for the degree of commutativity is the absolute value $|xv - vx|$ of the difference between xv and vx (also called commutator)³⁵. If the commutator vanishes, i.e. if $|xv - vx| = 0$, then $xv = vx$ holds true and one has commutativity. The degree of commutativity (or non-commutativity) of position and velocity depends on the mass of the object, here the drop of wine. The commutator obeys the fundamental law

$$|xv - vx| = \frac{\hbar}{m}$$

where \hbar , called (reduced) Planck's constant, is a fundamental constant of nature. This law of nature is so fundamentally important, that as of May 20th, 2019, the SI-system of units was

³⁵The commutator measures the difference in action per kilogram arising from interchanging the order of observation of position and velocity. The units of xv and vx are those of specific action, i.e. action per kilogram of mass.

changed by setting the value of \hbar to the fixed and exact value of $(6.62607015 \times 10^{-34})/2\pi$ Js [3]. Inserting the mass $m = 1$ g of the drop of wine gives a value of roughly $1.05457 \times 10^{-31} \text{m}^2/\text{s}$ for the commutator, which is not zero, but very small. Indeed, it is too small to be measureable at present. This explains how the fundamental non-commutativity of accidents could escape attention for centuries.

The commutator increases when the mass of the wine drop shrinks. How big is the difference when the drop contains only a single water molecule³⁶? A single water molecule has a mass of $m = 2.9916 \times 10^{-26}$ kg. That gives a commutator of $3.5251 \times 10^{-9} \text{m}^2/\text{s}$, which is measurable with contemporary technology.

The non-commutativity of observable accidents such as position and velocity has dramatic consequences. It implies a “*proper dynamical composedness*” of microscopic reality in the sense of Spaemann. Its “*self-assertion*” expresses itself in strong fluctuations, and its “*teleological structure*” could be perceived in the principle of least action. It is almost as if something were at stake for elementary particles, namely not to get confined or localized too much. As a consequence there is no sense in speaking of the position or trajectory of an elementary particle. Another consequence of non-commutativity is that the influence of the measuring apparatus can no longer be neglected. Usually one assumes that the interaction with the measuring apparatus plays a minor role and does not change the *accidens* under observation. For non-commutative accidents this assumption is no longer valid. Indeed this can render the laws of logic, such as the *tertium non datur* or the distributive law, inapplicable to certain statements.

The far reaching consequences of the fundamental law of non-commutativity can also be seen from the fact that it has pro-

³⁶Wine consists of 80-85% water (see above).

foundly influenced not only physics, but also mathematics. Although in mathematics the multiplication of matrices is non-commutative, it is impossible to represent x and v in $|xv - vx| = \hbar/m$ by matrices. The reason is that the sum over all diagonal elements on the left hand side gives always zero while it does not vanish on the right. As a result the representation of x and v requires spaces with infinitely many dimensions known as Hilbert spaces. The peculiar abstractness of natural reality (see Jhn 1:1 and Jhn 1:3) manifests itself in mathematical theorems about non-commutativity. To quote Werner Heisenberg: “*The idea of an objective reality of the elementary particles has evaporated in a peculiar way, but not into the mist of some new, unclear or uncertain idea of reality, but into the transparent clarity of mathematics*”³⁷ [6, S.12].

3.4 Separation of Scales

One could now object that for transubstantiation the microphysical reality of wine and bread does not seriously matter, because there are many types of wine and bread, that differ in various accidents such as alcohol content or the percentage of starch. If macrophysically distinguishable types of wine and bread do not matter for transubstantiation, then unmeasurably small commutators should not matter either.

But this objection is contradicted by the dogma itself, according to which Christ is present in every small piece of the consecrated species no matter how tiny it becomes³⁸. Moreover, the

³⁷ “*Die Vorstellung von der objektiven Realität der Elementarteilchen hat sich also in einer merkwürdigen Weise verflüchtigt, nicht in den Nebel irgendeiner neuen, unklaren oder noch unverstandenen Wirklichkeitsvorstellung, sondern in die durchsichtige Klarheit der Mathematik*”.

³⁸ Si quis negaverit, in venerabili Sacramento Eucharistiae sub unaquaque specie, & sub singulis suisque speciebus, separationem facta, totum Christum contineri; anathema sit [10, Can.III]

semantic consistency of physics (see page 24 above) links macro-physical and microphysical reality.

Consider amylose and cellulose for illustration. Amylose is contained in the starch granules within bread or potatoes. Cellulose is contained in grass or wood. Both molecules are linear polysaccharides, i.e. polymers made of tens of thousands of identical glucose units linked together. In amylose the glucose units are linked by α -1,4-glycosidic bonds. In cellulose the glucose units are linked by β -1,4-glycosidic bonds. The difference is microscopic. It arises from shifting a single oxygen atom in every second glucose unit over a very tiny distance. This microscopic shift has macroscopic consequences. Amylose molecules tend to form helical coils like a spring. Cellulose molecules, however, are slightly more straight. The linearity of cellulose results in more hydrogen bonds between hydroxyl groups on adjacent chains allowing them to pack more closely into fibres. As a result cellulose shows little interaction with water or any other solvent. Human digestive juices contain amylase enzymes that can hydrolyse the α -glycosidic bonds of amylose (and amylopectin) to break the starch down into usable glucose units. But they lack enzymes to hydrolyse the β -glycosidic bonds in cellulose. One can digest bread and potatoes, but not grass or wood. A small atomic shift can render a piece of matter unsuitable for the sacrament.

The example illustrates the emergence of macroscopic qualities such as solubility in water from microscopic properties such as the location of single atoms or the shapes of molecules. The mathematical mechanism behind emergent properties in physics is oftentimes scale separation. Scale separation means a mathematical limit in which some quantity becomes infinite.

The transition between quantum behaviour and classical behaviour can be understood as a separation of scales. In the non-commutative quantum regime ($\hbar \neq 0$) the length scale over which the wave amplitude of matter waves varies is comparable to their

wavelength. In the commutative classical regime ($\hbar = 0$) the wavelength is much smaller. The length scale ratio diverges to infinity in the classical limit $\hbar \rightarrow 0$.

For light waves exactly the same separation of length scales is familiar when looking at shadows that are cast by an opaque object. From far away (i.e. in the classical limit) the shadow boundary appears sharp. Upon magnification of the shadow boundary the transition between the dark region and the lit region becomes continuous. The analogy between light waves and matter waves is mathematically perfect. Classical particles and trajectories emerge continuously from quantum mechanical matter waves in the same way as the light rays of geometrical optics emerge from the wave theory of light in the small wavelength limit. The sharp boundary or impenetrable surface of a macroscopic body becomes continuous and penetrable upon sufficient magnification.

An important caveat must be made: Not every macroscopic property emerges from the microphysical reality in this way. Evident examples are almost all biological phenomena. Even purely physical phenomena such as macroscopic equilibrium shapes of non-crystalline materials or macroscopic heat conduction have not been linked rigorously to the microphysical reality of quantized light. Many unsolved problems remain.

Irrespective of these deep and open problems the dogma, that Christ is present in every tiny piece of the consecrated species, naturally raises the question: Is Christ really present in every polysaccharide molecule of the consecrated host ?

4 The Real Presence

4.1 Temporal Limits

The catechism teaches that the real presence begins “*at the moment of the consecration*” and “*and endures as long as the Eucharistic species subsist*” [4, KKK 1377]:

Praesentia eucharistica Christi a momento incipit consecrationis et perdurat dum species subsistunt eucharisticae.

This formulation is imprecise because enunciating the consecration takes some time, while transubstantiation is instantaneous according to St. Thomas (Tertia Pars Summae Theologiae, Quaestio LXXV, Articulus VII). When exactly does the real presence begin? Already when the first word “*Hoc*” is spoken or later? The Council of Trent teaches more precisely than the catechism that the real presence begins “*statim post*”, which means immediately after, consecration [10, Cap.III]:

...Et semper haec fides in Ecclesia Dei fuit, statim post consecrationem verum Domini nostri corpus, verumque eius sanguinem sub panis, Et vini specie una cum ipsius anima, Et divinitate existere;

There is agreement that the real presence lasts as long as the eucharistic species of wine and bread exist.

4.2 Spatial Limits

Wine is liquid, bread is solid. Both have surfaces at which molecules are exchanged with the environment. Wine volatilizes, bread dries and sublimates. The degree depends on the thermodynamic accidents of the eucharistic species and their environment.

The dogma seemingly teaches an unlimited divisibility of Christ in the eucharistic species.

Christus est totus integer sub unaquaque specierum et totus integer in earum partibus, ita ut panis fractio Christum non dividat.

in [4, KKK 1377], respectively

totus enim, & integer Christus sub panis specie, & sub quavis ipsius speciei parte, totus item sub vini specie, & sub eius partibus existit.

in [10, Cap.III]. Molecules and atoms are part of wine and bread. This raises the question whether Christ is also present whole and entire in every water molecule that has left the wine phase or the bread crumb. This would imply that Christ is present, in a microscopically dispersed manner, not only in the liquid phase within the chalice, but also in the gas phase near the chalice. Communion could then take place also through the nose.

But the dogmatic formulations speak of species. The eucharistic species have to remain recognizable also in their parts. The real presence is bound not only to temporal but also to spatial limits. This puts a lower bound on their divisibility.

A few water molecules do not make wine. It follows that the spatial limit of the real presence depends upon the recognizable reality of the converted species at hand. For wine, depending on its kind, a drop of roughly 100 nanometers in diameter should suffice to identify it. For bread however, such dimensions may well be too small, if coarser (pore) structures play a role.

5 Summary

- (i) What is meant with the substance of bread and wine?
According to St. Thomas Aquinas substance seems to be the individual underlying reality of things that is determined by accidents.
- (ii) What is the underlying reality of wine and bread?
The reality of all (living and non-living) material things is based in physics on the reality of electromagnetic and material quantum fields. Their accidental non-commutativity is most abstract.
- (iii) When and where begins and ends the real presence?
The real presence is linked dogmatically to the presence of the physical species of bread and wine. It seems desirable that the Church comments on the spatio-temporal limits by dismissing, confirming or stating these limits more precisely.

From the point of view of physics or natural philosophy there is no reason to doubt or dispute the dogma of transubstantiation. The physical reality of wine and bread is invisible quantized light (apart from tiny mass points). The dogma expresses rationally and without contradiction how Christ could be real-present under the physical species of wine and bread without violating the laws of the reality that He created through His word and that He keeps in existence through His truth (stability אמת, see page 19 above: “*et lex tua veritas*” Ps 118:142). To accept as true this possibility and the accompanying supernatural acts and events during eucharistic transubstantiation will therefore always remain a personal act of faith. An act that neither contradicts reason nor physical reality. On the contrary, it seems as if scientific reflection and religious contemplation could deepen one another.

Natural philosophy and physics can neither fathom nor explain the mystery of transubstantiation. In eucharistic transubstantia-

tion mostly invisible, carrier-free, strongly fluctuating, quantized but natural light, that gives rise to the accidents of bread and wine, is mysteriously transformed into invisible, carrier-free, supernatural, inaccessible divine light that gives rise to exactly the same accidents³⁹. In brief: Natural light becomes $\varphi\tilde{\omega}\varsigma$ ἀληθινόν⁴⁰, divine light.

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³⁹With respect to the closely related mystery of incarnation and hypostatic union it might be pointed out that, for natural electromagnetic light, the qualifications “unmixed” (ἀσυγχύτως, inconfuse), “unchangingly” (ἀτρέπτως, incommutabiliter), “unseparated” (ἀδιαρετως, inseparabiliter), and “undivided” (ἀχωρίστως, indivise) paraphrase very aptly the coexistence of visible and invisible light as well as to that of classical light and quantum light.

⁴⁰fittingly in Psalm 42 the priest prays for אֱמֶת (’Aemaet) and אוֹר (’Owr), i.e. for truth and light.

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