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A Review and Comparison of the "Substance Theory" with the "Quantum Theory"

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Abstract

Substance theory, or substance-attribute theory, is an ontological theory positing that objects are constituted each by a substance and properties borne by the substance but distinct from it. In this role, a substance can be referred to as a substratum or a thing-in-itself [1,2]. Substances are particulars that are ontologically independent: they are able to exist all by themselves [3,4]. Another defining feature often attributed to substances is their ability to undergo changes. Changes involve something existing before, during and after the change. They can be described in terms of a persisting substance gaining or losing properties [3]. Attributes or properties, on the other hand, are entities that can be exemplified by substances [5]. Properties characterize their bearers; they express what their bearer is like [4]. Substance is a key concept in ontology, the latter in turn part of metaphysics, which may be classified into monist, dualist, or pluralist varieties according to how many substances or individuals are said to populate, furnish, or exist in the world. According to monistic views, there is only one substance. Stoicism and Spinoza, for example, hold monistic views, that pneuma or God, respectively, is the one substance in the world. These modes of thinking are sometimes associated with the idea of immanence. Dualism sees the world as being composed of two fundamental substances (for example, the Cartesian substance dualism of mind and matter). Pluralist philosophies include Plato's Theory of Forms and Aristotle's hylomorphic categories.

Keywords: Philosophy; Chemistry; Substance theory; Quantum theory; Quantum

Introduction

Ancient Greek philosophy

Aristotle

Aristotle used the term "substance" (Greek: οὐσία ousia) in a secondary sense for genera and species understood as hylomorphic forms. Primarily, however, he used it with regard to his category of substance, the specimen ("this person" or "this horse") or individual, qua individual, who survives accidental change and in whom the essential properties in here that define those universals. A substance-that which is called a substance most strictly, primarily, and most of all-is that which is neither said of a subject nor in a subject, e.g., the individual man or the individual horse. The species in which the things primarily called substances are, are called secondary substances, as also are the genera of these species. For example, the individual man belongs in a species, man, and animal is a genus of the species; so, these-both man and animal-are called secondary substances [6].

Aristotle, Categories 2a13 (trans. J. L. Ackrill)

In chapter 6 of book, I the Physics Aristotle argues that any change must be analyzed in reference to the property of an invariant subject: as it was before the change and thereafter. Thus, in his hylomorphic account of change, matter serves as a relative substratum of transformation, i.e., of changing (substantial) form. In the Categories, properties are predicated only of substance, but in chapter 7 of book I of the Physics, Aristotle discusses substances coming to be and passing away in the "unqualified sense" wherein primary substances (πρῶται οὐσίαι; Categories 2a35) are generated from (or perish into) a material substratum by having gained (or lost) the essential property that formally defines substances of that kind (in the secondary sense). Examples of such a substantial change include not only conception and dying, but also metabolism, e.g., the bread a man eats becomes the man. On the other hand, in accidental change, because the essential property remains unchanged, by identifying the substance with its formal essence, substance may thereby serve as the relative subject matter or property-bearer of change in a qualified sense (i.e., barring matters of life or death). An example of this sort of accidental change is a change of color or size: a tomato becomes red, or a juvenile horse grows. Aristotle thinks that in addition to primary substances (which are particulars), there are secondary substances (δεύτεραι οὐσίαι), which are universals (Categories 2a11-a18) [7]. Neither the "bare particulars" nor "property bundles" of modern theory have their antecedent in Aristotle, according to whom all matter exists in some form. There is no prime matter or pure elements, there is always a mixture: a ratio weighing the four potential combinations of primary and secondary properties and analysed into discrete one-step and two-step abstract transmutations between the elements. However, according to Aristotle's theology, a form of invariant form exists without matter, beyond the cosmos, powerless and oblivious, in the eternal substance of the unmoved movers.

Pyrrhonism

Early Pyrrhonism rejected the idea that substances exist. Pyrrho put this as:

"Whoever wants to live well (eudaimonia) must consider these three questions: First, how are pragmata (ethical matters, affairs, topics) by nature? Secondly, what attitude should we adopt towards them? Thirdly, what will be the outcome for those who have this attitude?" Pyrrho's answer is that "As for pragmata they are all adiaphora (undifferentiated by a logical differentia), astathmēta (unstable, unbalanced, not measurable), and anepikrita (unjudged, unfixed, undecidable). Therefore, neither our sense-perceptions nor our doxai (views, theories, beliefs) tell us the truth or lie; so, we certainly should not rely on them. Rather, we should be adoxastoi (without views), aklineis (uninclined toward this side or that), and akradantoi (unwavering in our refusal to choose), saying about every single one that it no more is than it is not, or it both is and is not or it neither is nor is not [8].

Stoicism

The Stoics rejected the idea that incorporate beings are in here in matter, as taught by Plato. They believed that all beings are corporeal infused with a creative fire called pneuma. Thus, they developed a scheme of categories different from Aristotle's based on the ideas of Anaxagoras and Timaeus. The fundamental basis of Stoicism in this context was a universally consistent ethical and moral code that should be maintained at all times, the physical belief of beings as matter is an important philosophical footnote, as it marked the start of thinking as beings as inherently linked to reality, instead of to some abstract heaven [9,10].

Neoplatonism

Neoplatonists argue that beneath the surface phenomena that present themselves to our senses are three higher spiritual principles or hypostases, each one more sublime than the preceding. For Plotinus, these are the soul or world-soul, being/intellect or divine mind (nous), and "the one" [11].

Early Modern Philosophy

René Descartes means by a substance an entity which exists in such a way that it needs no other entity in order to exist. Therefore, only God is a substance in this strict sense. However, he extends the term to created things, which need only the concurrence of God to exist. He maintained that two of these are mind and body, each being distinct from the other in their attributes and therefore in their essence, and neither needing the other in order to exist. This is Descartes' substance dualism. Baruch Spinoza denied Descartes' "real distinction" between mind and matter. Substance, according to Spinoza, is one and indivisible, but has multiple "attributes". He regards an attribute, though, as "what we conceive as constituting the [single] essence of substance". The single essence of one substance can be conceived of as material and also, consistently, as mental. What is ordinarily called the natural world, together with all the individuals in it, is immanent in God: hence his famous phrase deus sive natura ("God or Nature").

John Locke views substance through a corpuscularian lens where it exhibits two types of qualities which stem from a source. He believes that humans are born tabula rasa or "blank slate" - without innate knowledge. In An Essay Concerning Human Understanding Locke writes that "first essence may be taken for the very being of anything, whereby it is, what it is." If humans are born without any knowledge, the way to receive knowledge is through perception of a certain object. But, according to Locke, an object exists in its primary qualities, no matter whether the human perceives it or not; it just exists. For example, an apple has qualities or properties that determine its existence apart from human perception of it, such as its mass or texture. The apple itself is also "pure substance in which is supposed to provide some sort of 'unknown support' to the observable qualities of things"[vague] that the human mind perceives [12]. The foundational or support qualities are called primary essences which "in the case of physical substances, are the underlying physical causes of the object's observable qualities" [13]. But then what is an object except "the owner or support of other properties"? Locke rejects Aristotle's category of the forms and develops mixed ideas about what substance or "first essence" means. Locke's solution to confusion about the first essence is to argue that objects simply are what they are - made up of microscopic particles existing because they exist. According to Locke, the mind cannot completely grasp the idea of a substance as it "always falls beyond knowledge" [14]. There is a gap between what first essence truly means and the mind's perception of it that Locke believes the mind cannot bridge objects in their primary qualities must exist apart from human perception.

The molecular combination of atoms in first essence then forms the solid base that humans can perceive and add qualities to describe - the only way humans can possibly begin to perceive an object. The way to perceive the qualities of an apple is from the combination of the primary qualities to form the secondary qualities. These qualities are then used to group the substances into different categories that "depend on the properties [humans] happen to be able to perceive" [14]. The taste of an apple or the

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feeling of its smoothness are not traits inherent to the fruit but are the power of the primary qualities to produce an idea about that object in the mind [15]. The reason that humans can't sense the actual primary qualities is the mental distance from the object; thus, Locke argues, objects remain nominal for humans [16]. Therefore, the argument then returns to how "a philosopher has no other idea of those substances than what is framed by a collection of those simple ideas which are found in them" [17]. The mind's conception of substances "is complex rather than simple" and "has no (supposedly innate) clear and distinct idea of matter that can be revealed through intellectual abstraction away from sensory qualities" [12].

The last quality of substance is the way the perceived qualities seem to begin to change - such as a candle melting; this quality is called the tertiary quality. Tertiary qualities "of a body are those powers in it that, by virtue of its primary qualities, give it the power to produce observable changes in the primary qualities of other bodies"; "the power of the sun to melt wax is a tertiary quality of the sun" [13]. They are "mere powers; qualities such as flexibility, ductility; and the power of sun to melt wax". This goes along with "passive power: the capacity a thing has for being changed by another thing" [18]. In any object, at the core are the primary qualities (unknowable by the human mind), the secondary quality (how primary qualities are perceived), and tertiary qualities (the power of the combined qualities to make a change to the object itself or to other objects).

Robert Boyle's corpuscularian hypothesis states that "all material bodies are composites of ultimately small[vague] particles of matter" that "have the same material qualities[vague] as the larger composite bodies do" [19]. Using this basis, Locke defines his first group, primary qualities, as "the ones that a body doesn't lose, however much it alters"[20]. The materials retain their primary qualities even if they are broken down because of the unchanging nature of their atomic particles [19]. If someone is curious about an object and they who? say it is solid and extended, these two descriptors are primary qualities [21]. The second group consists of secondary qualities which are "really nothing but the powers to produce various sensations in us by their primary qualities"[22]. Locke argues that the impressions our senses perceive from the objects (i.e., taste, sounds, colors, etc.) are not natural properties of the object itself, but things they induce in us by means of the "size, shape, texture, and motion of their imperceptible parts" [22] The bodies send insensible particles to our senses which let us perceive the object through different faculties; what we perceive is based on the object's composition. With these qualities, people can achieve the object through bringing "co-existing powers and sensible qualities to a common ground for explanation" [23]. Locke supposes that one wants to know what "binds these qualities" into an object, and argues that a "substratum" or "substance" has this effect, defining "substance" as follows: The idea of ours to which we give the general name substance, being nothing but the supposed but unknown support of those qualities we find existing and which we imagine can't exist sine re substante - that is, without something to support them - we call that support substantia; which, according to the true meaning of the word, is in plain English standing under or upholding.

John Locke, An Essay Concerning Human Understanding; book 2, chapter 23 [24]: This substratum is a construct of the mind in an attempt to bind all the qualities seen together; it is only "a supposition of an unknown support of qualities that are able to cause simple ideas in us."[24] Without making a substratum, people would be at a loss as to how different qualities relate. Locke does, however, mention that this substratum is an unknown, relating it to the story of the world on the turtle's back and how the believers eventually had to concede that the turtle just rested on "something he knew not what".[24] This is how the mind perceives all things and from which it can make ideas about them; it is entirely relative, but it does provide a "regularity and consistency to our ideas". [21] Substance, overall, has two sets of qualities - those that define it, and those related to how we perceive it. These qualities rush to our minds, which must organize them. As a result, our mind creates a substratum (or substance) for these objects, into which it groups related qualities.

Criticism of Soul as Substance

Kant observed that the assertion of a spiritual soul as substance could be a synthetic proposition which, however, was unproved and completely arbitrary.[25] Introspection does not reveal any diachronic substrate remaining unchanged throughout life. The temporal structure of consciousness is retentive-perceptive-prognostic. The selfhood arises as result of several informative flows: (1) signals from our own body; (2) retrieved memories and forecasts; (3) the affective load: dispositions and aversions; (4) reflections in other minds.[26] Mental acts have the feature of appropriation: they are always attached to some pre-reflective consciousness.[27] As visual perception is only possible from a definite point of view, so inner experience is given together with self-consciousness. The latter is not an autonomous mental act, but a formal way how the first person has their experience. From the pre-reflective consciousness, the person gains conviction of their existence. This conviction is immune to false reference.[28] The concept of person is prior to the concepts of subject and body.[29] The reflective self-consciousness is a conceptual and elaborate cognition. Selfhood is a self-constituting effigy, a task to be accomplished [30]. Humans are incapable of comprising all their experience within the current state of consciousness; overlapping memories are critical for personal integrity. Appropriated experience can be recollected. At stage B, we remember the experience of stage A; at stage C, we may be aware of the mental acts of stage B. The idea of self-identity is enforced by the relatively slow changes of our body and social situation.[31] Personal identity may be explained without accepting a spiritual agent as subject of mental activity. [32] Associative connection between life episodes is necessary and sufficient for the maintenance of a united selfhood. Personal

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character and memories can persist after radical mutation of the body.[33]

Irreducible Concepts

Two irreducible concepts encountered in substance theory are the bare particular and inherence.

Bare Particular

In substance theory, a bare particular of an object is the element without which the object would not exist, that is, its substance, which exists independently from its properties, even if it is impossible for it to lack properties entirely. It is "bare" because it is considered without its properties and "particular" because it is not abstract. The properties that the substance has are said to be inhered in the substance.

Inherence

Another primitive concept in substance theory is the inherence of properties within a substance. For example, in the sentence, "The apple is red" substance theory says that red inheres in the apple. Substance theory takes the meaning of an apple having the property of redness to be understood, and likewise that of a property's inherence in substance, which is similar to, but not identical with, being part of the substance.

The inverse relation is participation. Thus, in the example above, just as red inheres in the apple, so the apple participates in red.

Arguments Supporting the Theory

Two common arguments supporting substance theory are the argument from grammar and the argument from conception. The argument from grammar uses traditional grammar to support substance theory. For example, the sentence "Snow is white" contains a grammatical subject "snow" and the predicate "is white", thereby asserting snow is white. The argument holds that it makes no grammatical sense to speak of "whiteness" disembodied, without asserting that snow or something else is white. Meaningful assertions are formed by virtue of a grammatical subject, of which properties may be predicated, and in substance theory, such assertions are made with regard to a substance.

Bundle theory rejects the argument from grammar on the basis that a grammatical subject does not necessarily refer to a metaphysical subject. Bundle theory, for example, maintains that the grammatical subject of a statement refers to its properties. For example, a bundle theorist understands the grammatical subject of the sentence, "Snow is white", to be a bundle of properties such as white. Accordingly, one can make meaningful statements about bodies without referring to substances. Another argument for the substance theory is the argument from conception. The argument claims that in order to conceive of an object's properties, like the redness of an apple, one must conceive of the object that has those properties. According to the argument, one cannot conceive of redness, or any other property, distinct from the substance that has that property.

Criticism

The idea of substance was famously critiqued by David Hume,[34] who held that since substance cannot be perceived, it should not be assumed to exist.[35] Friedrich Nietzsche, and after him Martin Heidegger, Michel Foucault and Gilles Deleuze also rejected the notion of "substance", and in the same movement the concept of subject - seeing both concepts as holdovers from Platonic idealism. For this reason, Althusser's "anti-humanism" and Foucault's statements were criticized, by Jürgen Habermas and others, for misunderstanding that this led to a fatalist conception of social determinism. For Habermas, only a subjective form of liberty could be conceived, to the contrary of Deleuze who talks about "a life", as an impersonal and immanent form of liberty. For Heidegger, Descartes means by "substance" that by which "we can understand nothing else than an entity which is in such a way that it need no other entity in order to be." Therefore, only God is a substance as Ens perfectissimus (most perfect being). Heidegger showed the inextricable relationship between the concept of substance and of subject, which explains why, instead of talking about "man" or "humankind", he speaks about the Dasein, which is not a simple subject, nor a substance.[36] Alfred North Whitehead has argued that the concept of substance has only a limited applicability in everyday life and that metaphysics should rely upon the concept of process.[37] Roman Catholic theologian Karl Rahner, as part of his critique of transubstantiation, rejected substance theory and instead proposed the doctrine of transfinalization, which he felt was more attuned to modern philosophy. However, this doctrine was rejected by Pope Paul VI in his encyclical Mysterium fidei.

Bundle Theory

The bundle theorist's principal objections to substance theory concern the bare particulars of a substance, which substance theory considers independently of the substance's properties. The bundle theorist objects to the notion of a thing with no properties, claiming that such a thing is inconceivable and citing John Locke, who described a substance as "a something, I know not what." To the bundle theorist, as soon as one has any notion of a substance in mind, a property accompanies that notion.

Identity of Indiscernibles Counterargument

The indiscernibility argument from the substance theorist targets those bundle theorists who are also metaphysical realists. Metaphysical realism uses the identity of universals to compare and identify particulars. Substance theorists say that bundle theory is incompatible with metaphysical realism due to the identity of indiscernibles: particulars may differ from one another only with respect to their attributes or relations. The substance theorist's indiscernibility argument against the metaphysically realistic bundle theorist states that numerically different concrete

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particulars are discernible from the self-same concrete particular only by virtue of qualitatively different attributes.

The indiscernibility argument points out that if bundle theory and discernible concrete particulars theory explain the relationship between attributes, then the identity of indiscernibles theory must also be true. The indiscernibles argument then asserts that the identity of indiscernibles is violated, for example, by identical sheets of paper. All of their qualitative properties are the same (e.g., white, rectangular, 9 x 11 inches...) and thus, the argument claims, bundle theory and metaphysical realism cannot both be correct. However, bundle theory combined with trope theory (as opposed to metaphysical realism) avoids the indiscernibles argument because each attribute is a trope if can only be held by only one concrete particular.

The argument does not consider whether "position" should be considered an attribute or relation. It is after all through the differing positions that we in practice differentiate between otherwise identical pieces of paper.

Religious Philosophy

Christianity

The Christian writers of antiquity adhered to the Aristotelian conception of substance. Their peculiarity was the use of this idea for the discernment of theological nuances. Clement of Alexandria considered both material and spiritual substances: blood and milk; mind and soul, respectively. [38,39] Origen may be the first theologian expressing Christ's similarity with the Father as consubstantiality. Tertullian professed the same view in the West [40]. The ecclesiastics of the Cappadocian group (Basil of Caesarea, Gregory of Nyssa) taught that the Trinity had a single substance in three hypostases individualized by the relations among them. In later ages, the meaning of "substance" became more important because of the dogma of the Eucharist. Hildebert of Lavardin, archbishop of Tours, introduced the term transubstantiation about 1080; its use spread after the Fourth Council of the Lateran in 1215. According to Thomas Aquinas, beings may possess substance in three different modes. Together with other Medieval philosophers, he interpreted God's epithet "El Shaddai" (Genesis 17:1) as self-sufficient and concluded that God's essence was identical with existence.[41] Aquinas also deemed the substance of spiritual creatures identical with their essence (or form); therefore, he considered each angel to belong to its own distinct species.[citation needed] In Aquinas' view, composite substances consist of form and matter. Human substantial form, i.e., soul, receives its individuality from body.[42]

Buddhism

Buddhism rejects the concept of substance. Complex structures are comprehended as an aggregate of components without any essence. Just as the junction of parts is called cart, so the collections of elements are called things.[43] All formations are unstable (aniccā) and lacking any constant core or "self" (anattā).[44] Physical objects have no metaphysical substrate.[45] Arising entities hang on previous ones conditionally: in the notable teaching on interdependent origination, effects arise not as caused by agents but conditioned by former situations. Our senses, perception, feelings, wishes and consciousness are flowing, the view satkāya-dṛṣṭi of their permanent carrier is rejected as fallacious. The school of Madhyamaka, namely Nāgārjuna, introduced the idea of the ontological void (śūnyatā). The Buddhist metaphysics Abhidharma presumes particular forces which determine the origin, persistence, aging and decay of everything in the world. Vasubandhu added a special force making a human, called "aprāpti" or "pṛthagjanatvam".[46] Because of the absence of a substantial soul, the belief in personal immortality loses foundation.[47] Instead of deceased beings, new ones emerge whose fate is destined by the karmic law. The Buddha admitted the empirical identity of persons testified by their birth, name, and age. He approved the authorship of deeds and responsibility of performers.[48] The disciplinary practice in the Sangha including reproaches, confession and expiation of transgressions,[49] requires continuing personalities as its justification.

Wave functions of the electron in a hydrogen atom at different energy levels. Quantum mechanics cannot predict the exact location of a particle in space, only the probability of finding it at different locations.[1] The brighter areas represent a higher probability of finding the electron. Quantum mechanics is a fundamental theory in physics that provides a description of the physical properties of nature at the scale of atoms and subatomic particles.[2]:1.1 It is the foundation of all quantum physics including quantum chemistry, quantum field theory, quantum technology, and quantum information science. Classical physics, the collection of theories that existed before the advent of quantum mechanics, describes many aspects of nature at an ordinary (macroscopic) scale, but is not sufficient for describing them at small (atomic and subatomic) scales. Most theories in classical physics can be derived from quantum mechanics as an approximation valid at large (macroscopic) scale.[3]

Quantum mechanics differs from classical physics in that energy, momentum, angular momentum, and other quantities of a bound system are restricted to discrete values (quantization); objects have characteristics of both particles and waves (wave-particle duality); and there are limits to how accurately the value of a physical quantity can be predicted prior to its measurement, given a complete set of initial conditions (the uncertainty principle). Quantum mechanics arose gradually from theories to explain observations that could not be reconciled with classical physics, such as Max Planck's solution in 1900 to the black-body radiation problem, and the correspondence between energy and frequency in Albert Einstein's 1905 paper, which explained the photoelectric effect. These early attempts to understand microscopic phenomena, now known as the "old quantum theory", led to the full development of quantum mechanics in the mid-

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1920s by Niels Bohr, Erwin Schrödinger, Werner Heisenberg, Max Born, Paul Dirac and others. The modern theory is formulated in various specially developed mathematical formalisms. In one of them, a mathematical entity called the wave function provides information, in the form of probability amplitudes, about what measurements of a particle's energy, momentum, and other physical properties may yield.

Overview and Fundamental Concepts

Quantum mechanics allows the calculation of properties and behaviour of physical systems. It is typically applied to microscopic systems: molecules, atoms and sub-atomic particles. It has been demonstrated to hold for complex molecules with thousands of atoms,[4] but its application to human beings raises philosophical problems, such as Wigner's friend, and its application to the universe as a whole remains speculative.[5] Predictions of quantum mechanics have been verified experimentally to an extremely high degree of accuracy [note 1].

A fundamental feature of the theory is that it usually cannot predict with certainty what will happen, but only gives probabilities. Mathematically, a probability is found by taking the square of the absolute value of a complex number, known as a probability amplitude. This is known as the Born rule, named after physicist Max Born. For example, a quantum particle like an electron can be described by a wave function, which associates to each point in space a probability amplitude. Applying the Born rule to these amplitudes gives a probability density function for the position that the electron will be found to have when an experiment is performed to measure it. This is the best the theory can do; it cannot say for certain where the electron will be found. The Schrödinger equation relates the collection of probability amplitudes that pertain to one moment of time to the collection of probability amplitudes that pertain to another.

One consequence of the mathematical rules of quantum mechanics is a tradeoff in predictability between different measurable quantities. The most famous form of this uncertainty principle says that no matter how a quantum particle is prepared or how carefully experiments upon it are arranged, it is impossible to have a precise prediction for a measurement of its position and also at the same time for a measurement of its momentum. Another consequence of the mathematical rules of quantum mechanics is the phenomenon of quantum interference, which is often illustrated with the double-slit experiment. In the basic version of this experiment, a coherent light source, such as a laser beam, illuminates a plate pierced by two parallel slits, and the light passing through the slits is observed on a screen behind the plate.[6]:102-111[2]:1.1-1.8 The wave nature of light causes the light waves passing through the two slits to interfere, producing bright and dark bands on the screen - a result that would not be expected if light consisted of classical particles.[6] However, the light is always found to be absorbed at the screen at discrete points, as individual particles rather than waves; the interference pattern appears via the varying density of these particle hits on the screen. Furthermore, versions of the experiment that include detectors at the slits find that each detected photon passes through one slit (as would a classical particle), and not through both slits (as would a wave).[6]:109[7,8] However, such experiments demonstrate that particles do not form the interference pattern if one detects which slit, they pass through. Other atomic-scale entities, such as electrons, are found to exhibit the same behavior when fired towards a double slit.[2] This behavior is known as wave-particle duality.

Another counter-intuitive phenomenon predicted by quantum mechanics is quantum tunnelling: a particle that goes up against a potential barrier can cross it, even if its kinetic energy is smaller than the maximum of the potential.[9] In classical mechanics this particle would be trapped. Quantum tunnelling has several important consequences, enabling radioactive decay, nuclear fusion in stars, and applications such as scanning tunnelling microscopy and the tunnel diode.[10] When quantum systems interact, the result can be the creation of quantum entanglement: their properties become so intertwined that a description of the whole solely in terms of the individual parts is no longer possible. Erwin Schrödinger called entanglement "...the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought"[11]. Quantum entanglement enables the counter-intuitive properties of quantum pseudo-telepathy, and can be a valuable resource in communication protocols, such as quantum key distribution and superdense coding [12]. Contrary to popular misconception, entanglement does not allow sending signals faster than light, as demonstrated by the no-communication theorem [12].

Another possibility opened by entanglement is testing for "hidden variables", hypothetical properties more fundamental than the quantities addressed in quantum theory itself, knowledge of which would allow more exact predictions than quantum theory can provide. A collection of results, most significantly Bell's theorem, have demonstrated that broad classes of such hidden-variable theories are in fact incompatible with quantum physics. According to Bell's theorem, if nature actually operates in accord with any theory of local hidden variables, then the results of a Bell test will be constrained in a particular, quantifiable way. Many Bell tests have been performed, using entangled particles, and they have shown results incompatible with the constraints imposed by local hidden variables [13,14]. It is not possible to present these concepts in more than a superficial way without introducing the actual mathematics involved; understanding quantum mechanics requires not only manipulating complex numbers, but also linear algebra, differential equations, group theory, and other more advanced subjects.[note 2] Accordingly, this article will present a mathematical formulation of quantum mechanics and survey its application to some useful and oft-studied examples.

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Philosophical Implications

Unsolved Problem in Physics:

Is there a preferred interpretation of quantum mechanics? How does the quantum description of reality, which includes elements such as the “superposition of states” and “wave function collapse”, give rise to the reality we perceive? (More unsolved problems in physics). Since its inception, the many counter-intuitive aspects and results of quantum mechanics have provoked strong philosophical debates and many interpretations. The arguments center on the probabilistic nature of quantum mechanics, the difficulties with wavefunction collapse and the related measurement problem, and quantum nonlocality. Perhaps the only consensus that exists about these issues is that there is no consensus. Richard Feynman once said, “I think I can safely say that nobody understands quantum mechanics” [42]. According to Steven Weinberg, “There is now in my opinion no entirely satisfactory interpretation of quantum mechanics”[43].

The views of Niels Bohr, Werner Heisenberg and other physicists are often grouped together as the “Copenhagen interpretation” [44,45]. According to these views, the probabilistic nature of quantum mechanics is not a temporary feature which will eventually be replaced by a deterministic theory but is instead a final renunciation of the classical idea of “causality”. Bohr in particular emphasized that any well-defined application of the quantum mechanical formalism must always make reference to the experimental arrangement, due to the complementary nature of evidence obtained under different experimental situations. Copenhagen-type interpretations remain popular in the 21st century [46,50].

Albert Einstein, himself one of the founders of quantum theory, was troubled by its apparent failure to respect some cherished metaphysical principles, such as determinism and locality. Einstein’s long-running exchanges with Bohr about the meaning and status of quantum mechanics are now known as the Bohr-Einstein debates. Einstein believed that underlying quantum mechanics must be a theory that explicitly forbids action at a distance. He argued that quantum mechanics was incomplete, a theory that was valid but not fundamental, analogous to how thermodynamics is valid, but the fundamental theory behind it is statistical mechanics. In 1935, Einstein and his collaborators Boris Podolsky and Nathan Rosen published an argument that the principle of locality implies the incompleteness of quantum mechanics, a thought experiment later termed the Einstein-Podolsky-Rosen paradox.[note 6] In 1964, John Bell showed that EPR’s principle of locality, together with determinism, was actually incompatible with quantum mechanics: they implied constraints on the correlations produced by distance systems, now known as Bell inequalities, that can be violated by entangled particles [51]. Since then, several experiments have been performed to obtain these correlations, with the result that they do in fact violate Bell inequalities, and thus falsify the conjunction of locality with determinism [13,14]. Bohmian mechanics shows that it is possible to reformulate quantum mechanics to make it deterministic, at the price of making it explicitly nonlocal. It attributes not only a wave function to a physical system, but in addition a real position, that evolves deterministically under a nonlocal guiding equation. The evolution of a physical system is given at all times by the Schrödinger equation together with the guiding equation; there is never a collapse of the wave function. This solves the measurement problem [52].

Everett’s many-worlds interpretation, formulated in 1956, holds that all the possibilities described by quantum theory simultaneously occur in a multiverse composed of mostly independent parallel universes [53]. This is a consequence of removing the axiom of the collapse of the wave packet. All possible states of the measured system and the measuring apparatus, together with the observer, are present in a real physical quantum superposition. While the multiverse is deterministic, we perceive non-deterministic behavior governed by probabilities, because we don’t observe the multiverse as a whole, but only one parallel universe at a time. Exactly how this is supposed to work has been the subject of much debate. Several attempts have been made to make sense of this and derive the Born rule,[54,55] with no consensus on whether they have been successful [56-58]. Relational quantum mechanics appeared in the late 1990s as a modern derivative of Copenhagen-type ideas,[59] and QBism was developed some years later [60].

History

Max Planck is Considered the Father of The Quantum Theory.

Quantum mechanics was developed in the early decades of the 20th century, driven by the need to explain phenomena that, in some cases, had been observed in earlier times. Scientific inquiry into the wave nature of light began in the 17th and 18th centuries, when scientists such as Robert Hooke, Christiaan Huygens and Leonhard Euler proposed a wave theory of light based on experimental observations [61]. In 1803 English polymath Thomas Young described the famous double-slit experiment [62]. This experiment played a major role in the general acceptance of the wave theory of light.

During the early 19th century, chemical research by John Dalton and Amedeo Avogadro lent weight to the atomic theory of matter, an idea that James Clerk Maxwell, Ludwig Boltzmann and others built upon to establish the kinetic theory of gases. The successes of kinetic theory gave further credence to the idea that matter is composed of atoms, yet the theory also had shortcomings that would only be resolved by the development of quantum mechanics [63]. While the early conception of atoms from Greek philosophy had been that they were indivisible units - the word “atom” deriving from the Greek for “uncuttable” - the 19th century saw the formulation of hypotheses about subatomic

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structure. One important discovery in that regard was Michael Faraday's 1838 observation of a glow caused by an electrical discharge inside a glass tube containing gas at low pressure. Julius Plücker, Johann Wilhelm Hittorf and Eugen Goldstein carried on and improved upon Faraday's work, leading to the identification of cathode rays, which J. J. Thomson found to consist of subatomic particles that would be called electrons [64,65].

The black-body radiation problem was discovered by Gustav Kirchhoff in 1859. In 1900, Max Planck proposed the hypothesis that energy is radiated and absorbed in discrete "quanta" (or energy packets), yielding a calculation that precisely matched the observed patterns of black-body radiation [66]. The word quantum derives from the Latin, meaning "how great" or "how much" [67]. According to Planck, quantities of energy could be thought of as divided into "elements" whose size (E) would be proportional to their frequency (ν): where h is Planck's constant. Planck cautiously insisted that this was only an aspect of the processes of absorption and emission of radiation and was not the physical reality of the radiation [68]. In fact, he considered his quantum hypothesis a mathematical trick to get the right answer rather than a sizable discovery [69]. However, in 1905 Albert Einstein interpreted Planck's quantum hypothesis realistically and used it to explain the photoelectric effect, in which shining light on certain materials can eject electrons from the material. Niels Bohr then developed Planck's ideas about radiation into a model of the hydrogen atom that successfully predicted the spectral lines of hydrogen [70]. Einstein further developed this idea to show that an electromagnetic wave such as light could also be described as a particle (later called the photon), with a discrete amount of energy that depends on its frequency [71]. In his paper "On the Quantum Theory of Radiation," Einstein expanded on the interaction between energy and matter to explain the absorption and emission of energy by atoms. Although overshadowed at the time by his general theory of relativity, this paper articulated the mechanism underlying the stimulated emission of radiation,[72] which became the basis of the laser.

The 1927 Solvay Conference in Brussels was the fifth world physics conference. This phase is known as the old quantum theory. Never complete or self-consistent, the old quantum theory was rather a set of heuristic corrections to classical mechanics [73]. The theory is now understood as a semi-classical approximation [74] to modern quantum mechanics [75]. Notable results from this period include, in addition to the work of Planck, Einstein and Bohr mentioned above, Einstein and Peter Debye's work on the specific heat of solids, Bohr and Hendrika Johanna van Leeuwen's proof that classical physics cannot account for diamagnetism, and Arnold Sommerfeld's extension of the Bohr model to include special-relativistic effects.

In the mid-1920s quantum mechanics was developed to become the standard formulation for atomic physics. In 1923, the French physicist Louis de Broglie put forward his theory of matter waves by stating that particles can exhibit wave characteristics and vice versa. Building on de Broglie's approach, modern quantum mechanics was born in 1925, when the German physicists Werner Heisenberg, Max Born, and Pascual Jordan [76,77] developed matrix mechanics and the Austrian physicist Erwin Schrödinger invented wave mechanics. Born introduced the probabilistic interpretation of Schrödinger's wave function in July 1926 [78]. Thus, the entire field of quantum physics emerged, leading to its wider acceptance at the Fifth Solvay Conference in 1927 [79].

By 1930 quantum mechanics had been further unified and formalized by David Hilbert, Paul Dirac and John von Neumann [80] with greater emphasis on measurement, the statistical nature of our knowledge of reality, and philosophical speculation about the 'observer'. It has since permeated many disciplines, including quantum chemistry, quantum electronics, quantum optics, and quantum information science. It also provides a useful framework for many features of the modern periodic table of elements and describes the behaviors of atoms during chemical bonding and the flow of electrons in computer semiconductors, and therefore plays a crucial role in many modern technologies. While quantum mechanics was constructed to describe the world of the very small, it is also needed to explain some macroscopic phenomena such as superconductors [81-95] and superfluids.

Since the failure of both pure corpuscular and pure wave philosophies of nature, process theories assume that only events need to exist in order to have a physics. Starting from an ontology of actual events, a dispositional analysis is shown here to lead to a new idea of substance, that of a 'distribution of potentiality or propensity'. This begins to provide a useful foundation for quantum physics. A model is presented to show how the existence of physical substances could be a reasonable consequence of a theory of processes.

Aristotle, Descartes and Boyle all thought they had formed definite ideas about what it was to be a substance in the natural world. Their ideas were all different, however, so they cannot all have been correct. Aristotle's views held sway up to the beginning of modern science, at which point Boyle's corpuscular theory became more popular. His notion of an extended, impenetrable and eternal `material substance' was accepted by Locke and Newton, and as it became part of classical physics, it was thought to be clearly understood.

Modern physics however has rendered this certainty obsolete. Although quantum physics may predict the observable phenomena of nature exceedingly well, the idea of `natural substance' has become more mysterious, not less. Quantum physics postulates a wave function which seems to adequately describe natural probabilities, but no-one is clear what is described by this wave function. No-one knows what it is that exists with the form of this wave. Some interpreters of quantum mechanics have (not without justification) said that it is our knowledge that is described by

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the quantum wave function. Alternatively, seeking something more objective, we can have `processes' or `patterns of activity' in various forms. In the Copenhagen Interpretation the question is not answered, as the unit of activity - the `quantum of action' - is assumed to have an intrinsic wholeness which cannot be analysed further. Achieving a full understanding of `substance' in the quantum world seems to have become an impossible dream.

In the quantum world it is not substances but events and interactions which have become much more `real', definite and understandable. In Whitehead's process theory, it is only events which are the `actual entities' in the physical world. Substances are relegated to being `chains' or `societies' of these actual entities, and thus seem to have a more nominal than real existence. Physicists such as H.P. Stapp (1977) have tried to apply these process ideas to give a more comprehensive interpretation of quantum physics. Stapp nevertheless has had to postulate additional `geodesics' which carry mass and energy between events. In this paper I wish to show that if we were to start from a simple process world of events, and supplement this by some kind of causal analysis, we can be led to a concept of substance. This new derived concept, despite its novel pedigree from the theories of process and causation, will turn out to satisfy many if not all of the traditional concepts of `substance' as a `substratum which underlies time and change' (although its persistence will often be limited).

We must consider two cases. The actual events may either succeed each other continuously in time or have non-zero-time intervals between them. These two cases roughly characterize the difference between classical physics and quantum physics. If the actual events succeed each other continuously in time, then one can identify a continuously existing substance by that varying entity whose form at each time is just the actual event at that time. That substance would hence be actual and definite in the same way as the original events. It would persist continuously and be like a Democritean Atom or Boylean Corpuscle. This is the idea taken up in classical physics, where the corpuscles or particles are conceived to be fully and continuously existing in full actuality.

If the actual events exist only intermittently, however, any substances will have to span the temporal gaps between them, and the problem of finding an enduring substance is more difficult. This case, in which only some events are actual and completely definite, is the one considered in more detail here. Our aim is to derive a concept of substance independently of classical physics, so we can bypass some unwanted meanings that have accumulated from material corpuscularism. In this way, we can perhaps regain some of the insights of Aristotle, Aquinas, and Locke concerning substances. The independence from classical physics proves to be especially valuable in coming to understand quantum physics, as we can define what I believe is a coherent notion of a `quantum substance' which renders intelligible a number of the pecularities of quantum physics.

Traditional Views of Substances

There have been two (at least) extremal positions possible in philosophy with regard to any changeable enduring substance. One position is exemplified by Spinoza and Leibniz, who defined substance as `that whose nature requires its separate existence'. On this view, substances are self-sufficient beings which contain within themselves the complete source of all their changes. Leibiz has for example that all natural changes of his monads come from within, as `an external cause can have no influence upon its inner being' (Leibniz, 1714, ¶ 11). The difficulty then, as Kant (1747, § 7) realised, is that on this account `it is not necessary for [a substance's] existence that it stand in relation to other things'. It is a puzzle, on this account, why substances even have positional relations that might enable the acting of one substance on another. The possibility of interactions of substances can only be regained by denying that substances are self-sufficient beings. In this paper, I want to deny that substances are fully actual and determinate with respect to external interactions. I want to look for some closer relation between substances and `powers' or `propensities', in order that substances may endure through changes in some of their properties (their `accidents') produced by interactions withother substances.

If substances were self-sufficient, there is always the difficult question of how their powers for interacting are supposed to be related to their `underlying' nature. It is not clear, furthermore, whether it is possible to properly conceive of any `naked substance' apart from all its powers. Locke explicitly had no clear idea of the relation between a substance and its powers, and it is debateable (see M.R. Ayers (1975) whether he distinguished any power-less substance. One view is that of Boscovich, Faraday and Harré, whereby a substance is at a single place at any given time, around which its powers are `fields of force'. All inertia still resides in the point substance, and around it the field of force extends away indefinitely. However, it is still not perfectly clear how these `point centres of mutual influence' are related to the extended fields.

The second general position is the denial of `substance' altogether, and of any sense of continued identity, in favour of pure process. We then have a pure event or flux philosophy. Reasons for this repudiation have varied. Sometimes it has been the alleged unknowability of the real constitution of substances. At other times it has been a preference for `flux' or `creativity' as against the `Parmenidean influence' that is seen to pervade much of Western philosophy. Hume and Whitehead are perhaps the two most prominent figures here. Also, between the wars this century an ontology of `events' became widespread, especially because of a common interpretation of relativity theory and a positivistic approach to metaphysics. Russell's The Analysis of Matter (1927) is a good presentation of this position, wherein events are fixed in space and time. Paradoxically, they become then like fixed substances, and the understanding of event as `change' often fades.

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After the Second World War, as Nicholas Rescher (1962) notes, there was a general reaction to such an extreme event-and-no-continuant ontology. Many writers now repudiate `events' in favour of substances and their relations. In the reaction, however, a very uncritical idea of `substance' was taken over, practically identical with `material object'. This has result that there could be no very precise understanding of either the fact or the dynamics of real change. With some philosophers, nevertheless, the realization of the inadequacy of the event ontology came more moderately, and arguments were found for an ontology in which there are both events and continuants. Events could now be properly construed as real changes, by reference to the changes of the continuants involved. This was done as early as W.E. Johnson (1924), who was trying to counterbalance the middle Whitehead's Concept of Nature: it was Johnson who coined the term `continuant'. Without such a term, he remarks (1924, III, p. 127), it would be impossible to distinguish the case of two events A, B, say, causing two later events C & D, respectively, from their causing D & C, respectively. The necessity for substantial continuants was further supported by Reck (1958), who argued against an ontology of only events, and for a position closer to that of Johnson. However, neither Johnson nor Reck attacked the problem of giving a fully-fledged account of such continuants: they did not consider the problem, for example, of how a substance is related to its powers.

The present inquiry will therefore have as one of its starting points a process theory of discrete events and will proceed with the help of Leclerc (1972). Since some notions of propensities are required in any useful science or philosophy of nature (see Thompson, 1988b), processes will be analysed on this basis. We are led to postulate a new notion of `propensity fields', to see whether such things can continuously endure through certain types of interactions, and then to see whether we can identify these propensity fields with the `substances' of classical philosophy. I will use however Johnson's (1924) term `continuant' to avoid a number of unwanted associations from the history of the term `substance'

The Analysis of Event Causation

The basic notion of how one event causes another event is rather a complex one, and I think that it can be usefully `unpacked' into a number of perhaps more basic notions. This analysis follows Leclerc (1972,chs. 25 & 26) in taking modal considerations seriously. It is summarised as follows. Suppose an actual event A, say, causes an actual event B. This causation may be deterministic or indeterministic. Then the fact of that causation implies. That the event B was possible, That there must have been a real and active power or propensity to make B happen rather than remain only possible, That the power or propensity must at least have been directed to the occurrence of B, that there was a set of possibilities for the change. This set may have members apart from the possibility for B, and its members form a `space-time' of possibilities for change, only one of which actually occurs, That these various possibilities are related to each other in some structure, and that there was a form of distribution of the power or propensity over the set of possibilities, since, in general, not all possibilities are equally likely. For example, suppose event A is the emission of a electron from a negatively charged cathode, and event B is its hitting and exposing a grain on a photographic plate.

Then it must have been possible for the electron to hit the photographic plate, and There was an electrostatic propensity to repel the electron, rather than let it stay where it was when emitted. The electron and the photographic plate had propensities to interact with each other, rather than simply pass through each other unchanged. The propensities of (2) are all propensities for the named occurrences (repulsions and interacting, respectively), if there are quantum effects in the electron's travelling, and these are objectively random, there are a large number of possibilities for the interaction B, as it can at least occur at different positions on and in the photographic plate, and at different times, and These different places are related by being in a four-dimensional `space-time', this being the combination of different positions in the three-dimensional volume of the plate with different (one dimensional) times. These places have metric distances from each other, and temporal intervals between them. These different places each have their own propensity (and hence probability) for being where B actually happens. The distribution is given according to the square-modulus the quantum mechanical wave function

On Active Propensities

These implications amount to a causal or dispositional analysis of the sequence of events. Some philosophers do not believe that such an analysis is necessary, desirable, or even possible, as they see the realistic notions of `power' and `propensity' used here as not sufficiently scientific or definite to be satisfactory. I have argued, however, in a previous paper (Thompson, 1988b) that some notions of `real dispositions' are necessary for activities in both science and elsewhere, and that, however much we may dislike these ideas, they need to be examined closely and used carefully. I argued that, for both theoretical and practical reasons, we do have to take certain modal considerations seriously, and find realistic foundations for them. The implications listed above are an attempt to analyse closely the structure of real dispositions in the physical world.

By `power' of course is not meant `energy flow per unit time', but a general `capability' or `dispositional property' to act in a certain manner, as in Harré (1970a) or Ducasse (1964). The notion of `power or propensity' here has a long pre-scientific history as the specific `potential', `active force', `motive power', `drive', `impetus', `spring of activity', or `dynamicism' for change. For the purposes of analysing events on a causal basis, however, from these ideas I take simply `that which is necessary to make any change in fact occur' In traditional philosophy, the concept of `power' or `propensity' has had a varied history. It appears mostly in the works of Aristotle, Locke (1706, Bk. II, ch. XXI), Leibniz, and the proponents of `dynamic matter' such as Boscovich (1763),

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Priestley (1777), and Faraday (see Levere, 1968). In this century, it has been advocated by Bergson, Ushenko (1946) and Harré (1970a), but not all of these accounts are equally satisfactory for the present purposes. When Whitehead uses `real potentiality', for example, he emphasises the `possibility' aspect, and ignores the `power or propensity' component. In Whitehead's event philosophy, as Ushenko and Leclerc pointed out, there is no concept of active power, yet some such notion, one would think, would have a central role in any adequate theory of process.

In the sense that we require, `power' and `propensity' must mean more than `passive capacities' for being formed (as in the Thomist schools). We need to include the active powers that are in an agent that could actually initiate such forming. Any passive capacities or `liabilities' can be regarded as special cases of a more general sense. They could be regarded as `weaker powers', for example, compared with those of an active agent. One criticism of the use of powers and propensities is that they are used in a very general sense to refer to any capacity for any change, and that this sense is so general that its theoretical and empirical content for any explanation is low. It becomes too easy, the critics say, to postulate many distinct ad hoc powers which have no specific mutual relations: one for each change possible. Just how many distinct capabilities does a complex biological organism have, considering the great many situations in which it may be found, and the great many internal states that are possible for it? And how many powers does opium have, along with its `dormative virtue'?

This criticism is justified, but that does not mean that there are no such things as powers or propensities. The world would be a very peculiar place if people and objects had no capacities or propensities apart from what they actually did. In the history of the sciences of matter, admittedly, the notion of `power' tended to be abolished in favour of matter as corpuscular and purely actual. However elegant the motives and results of this tendency may have been, it is nevertheless inadequate both empirically and theoretically. Scientists from Newton on soon found themselves compelled to postulate powers of attraction and repulsion, and Faraday found that for electric and magnetic effects more complicated notions of forces and potentials are required. The task of science should be to reduce the number of different types of propensities needed to explain experimental phenomena, but for reasons given in Thompson (1988b), this number will never be reduced to zero.

Propensity Fields

Places in Space and Time

In section 3 we saw that for an actual event A to cause an actual event B, there was a set of possibilities for the change. This set may have members apart from the possibility for B, and its members form a `space-time' of possibilities for change, only one of which actually occurs. We can now identify (following Leclerc, 1972) places in space-time as just these `possibilities for actuality'. We can then say that the event is at a place when that possibility is being realised, and that this results in that place being `filled'. Since what is actual is at least possible, the set of filled places is a changing subset of the set of all places possible in the world. These places are being regarded as `wheres' and `whens'. That is, in the terminology of modern physics, places are places in space-time, not just in space. This is especially important if these places are to be the possibilities for events, for two events at different times, even though perhaps at the same spatial location, are always distinct: they realise different possibilities. This consideration is independent of any requirements of relativity theory, as it can be used with both Newtonian and Einsteinian space and time. The account of time implied here is that in which only the past is actual and definite, and the present is the process of `becoming' or `coming to be' of this definite past. This view was held by Whitehead (1929) and by C.D. Broad (1923). How this theory of time overcomes the objections of McTaggart has been outlined by Broad (see also Thompson, 1988a).

If the events being considered are ordinary physical events such as interactions, collisions, etc., in our everyday three-dimensional space and time, then places (as `possibilities for these events') can be identified with distinct regions of spacetime. The relational structure of implication no. 5 can be identified with the metric tensor that gathers regions into subsets of some larger space-time continuum. The theory of spacetime being developed here is closely related to Whitehead's notion of an `extensive continuum', which is the `coordination of all possible standpoints' (emphasis added). The discussion of whether this is an `absolute' or `relative' view of spacetime is beyond the scope of the present paper.

The events however need not be in our usual space and time: the analysis is quite general. Quantum mechanics postulates, for example, that particles with intrinsic spin have this spin `oriented' in a `spin space' distinct from our three dimensional space, and not simply embedded in it. Moreover, intrinsic spins have only a discrete range of possibilities. According to the process analysis of this paper, this is equivalent to saying that the spin can only range over a discrete set of `positions' or `places'. These places would be related to each other, in this case, as integers, or half-integral numbers.

On Real Possibilities

It is essential to remember that `places' are realistic possibilities, and are not merely abstract or de dicto possibilities such as those which arise when we might think or form propositions about what is possibly the case. Rather, we want here to have possibilites for physical events: possibilities which are relevant to what actually occurs. A great many de dicto possibilities are perfectly capable of being rationally entertained, but are nevertheless never possibilities for actualisation, either because they are not within the scope of physical laws, or because they are ruled out by the path that history has taken up to the present.

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The `possibilities for events' are not de re possibilities either. For de re possibilities involve particular objects, and here, the `possibilities for an event B' are distinguishable even if no such event occurs or exists in any way. They are certainly not `possible events', or any kind of events which in some way `subsist' without actually existing. As Quine (1961, p. 4) indicates, there are decided problems with the the notion of `possible entities'. Taken together, they seem to be part of an `over-populated universe'. ``Take, for instance, the possible fat man in the doorway; and, again, the possible bald man in that doorway. Are they the same possible man, or two possible men? How can we decide? How many possible men are there in that doorway?''.

There are severe problems for the application of identity-criteria to `possible entities', but not to the `possibilities for entities' discussed above. A `possibility for a fat man in the doorway', for example, is just any one of a number of regions in the doorway at some particular time, and these are identified and individuated by the usual spatio-temporal relations in an unambiguous fashion. The doorway may well contain a possibility for a fat man and/or a possibility for a bald man, but that does not require that we identify and individuate these `subsisting' men. We only need to identify the places which would be occupied if such men were to exist.

The important thing is to take possibilities seriously, and not to confuse them with actuality. From the mathematical point of view, for example, possibilities and actualities could be all grouped together in a one-level universe of Fregean `objects'. In mathematics, however, no distinctions are made between actualities and possibilities. From the point of view of extensional semantics, possibilities are just as much `objects' as actualities. This does not mean that, properly considered, actualities cannot be the realization of possibilities. As Whitehead put it (1929, p. 61), It cannot be too clearly understood that some chief notions of European thought were framed under the influence of a misapprehension, only partially corrected by the scientific progress of the last century. This mistake consists in the confusion of mere potentiality with actuality.

Field Distributions in Spacetime

If an actual event A causes an actual event B, then the fact of that causation implies that there was a form of distribution of the power or propensity over the set of possibilities, since, in general, not all possibilities are equally likely. The possibility which is eventually realized cannot just be the one with the greatest propensity, otherwise the competing alternatives with lesser propensities would not have been real possibilities in the first place. Allowing for a distribution of propensities means therefore allowing for a range of possibilities, each of which has some (i.e. non-zero) chance of occurring.

This was the sixth component of the analysis of section 3. We can now make this idea more concrete, by using the identification of these possibilities as places in spacetime. Since the `form of distribution of the power or propensity over the set of possibilities' now is seen to be a `form or distribution over regions of spacetime', it can best be represented as a field. It could be that powers and propensities have themselves some numerical measure, by means of positive real numbers representing probabilities for example. This field would then, in mathematical terms, be a positive scalar function over a subset of the four-dimensional continuum R4. In general, however, we do not have a priori reasons to choose that (or any) measure for the propensities themselves. More complicated measures may have to used, provided that some probability distribution can be derived for where the subsequent events are likely to occur. The Schrödinger equation in quantum mechanics, for example, uses a complex valued measure to describe the propensity distribution, and Dirac found it necessary to generalise this to a four-component complex-valued function, in order to describe both electron spins and anti-electrons in the same formalism. Whatever measure or descriptions of propensities may prove necessary, the notion of a field can be used to give the degree of propensity that is operative at each place in a spatiotemporal field.

Philosophically, what is important is that a particular propensity field can extend over many places, with different degrees of propensity at these different places, and not by itself single out any particular place in that region. The propensity field therefore extends over all places at which events `might have occurred', given the actual history of the world up to that point. Of course, one particular place will become selected once an event occurs, but this selection may well be objectively random in the sense that repetitions of this same history and of this same propensity distribution may result in the occurrence of different events. To recapitulate on the schema for causation that has been developed: we start considering the causal process with an event A, say, at some place pA in space and time. The propensities (which are responsible for making occur a successor event to A) therefore extend and endure through the spacetime continuum away from the place pA over places where successor events may occur. The exact spatio-temporal form of this field is given by a general field equation from a theory of physics, along with the boundary conditions that the field must be contiguous with the event at place pA.

Once the propensity field has been formed, it endures until its realization produces a new actual event B, say, at some place pB. If and when that realization occurs, there are produced further propensity fields which extend from the place pB and thus endure into the regions of spacetime to the future of B. The whole process is thus started over again. It is possible to say that the first propensity field becomes another, because the act that is the realization of the first field is simultaneously the act of forming the second, and because there is a spatio-temporal continuity between the initial and the final propensity distributions. The acts of `realizing' which have been discussed so far are somewhat simple, being the acting of just a simple homogeneous propensity field. It is much more

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likely that most events or acts are interactions, or the acting of one propensity field on another. As Leclerc (1972, ch. 23) points out, `actings on' always involve a reciprocal capacity to `receive' in that which is acted upon, so that aspects of capability or propensity are required in both the agent and in the patient. That most events are interactions is also supported by quantum physics, where events which are the spontaneous action of a single particle are comparatively rare, because events such as spontaneous decays are not the most common type.

If an interaction between two propensity fields is to result in an actual event at a particular place, it will be necessary for the two propensity fields to overlap in at least that region. It may be concluded that two propensity fields may only interact if they overlap in spacetime, and that, if they do interact to produce an actual event, then both the fields are reduced in spatial extent at the time of the event. The likellihood for specific interaction events occurring will again depend on the form or distribution of the measures of the two propensity fields, and it is likely that the probability of interaction will depend on something like the product of the two fields. Exactly how this works is of course for physics to determine.

Continuants (Substances) Which Endure Through Change?

We now come to the question of whether a concept of `substance', as at least `continuant', can be constructed using the above analysis of process and dispositions. A continuant has been defined by Johnson (1924, III p. xx) to be `that which continues to exist throughout some limited or unlimited period of time, during which its inner states or its outer connections may be altering or remain unaltered'. Johnson used the term `continuant' as against `substance', for the term `substance' is impaired by the fact that, in the history of philosophy, many diverse senses have been assigned to it, senses which give associations which are not wanted here. For example, though continuants can endure through change, they need only endure for at least a while, and not necessarily everlastingly, as many suppose that substances are required to do. (Leibniz, for example, argues from everlasting substances to immortality.) Further, since Locke at least, it has become obscure exactly how a substance is supposed to be related to its powers, qualities and properties, etc. `Substance' has come to be regarded as an `I know not what' which in some obscure manner `underlies' and `supports' its attributes. Ducasse (1964) has proposed `substant' for a new association-free term, but in some ways `continuant' is still preferable. This is because substants do more than just continue: Ducasse lists another five general features of substants, another five things which they are capable of doing:

- acting (as an 'enactor')
- being in a state (as a `tenant')
- affecting another substant (as an `agent')
- being affected by another (as a `patient'),
- changing into something completely different (as a `mutant'), as well as
- enduring changes (as a `continuant').

As all these details presuppose a detailed analysis of the concept we are constructing, I will use the term `continuant' to refer to any particular individual being in the world which can continue to exist at least for a while, and can effect and undergo some change while remaining the same being (`same' in some sense to be elucidated).

Unchanging Continuants

We will first consider what particular things can endure through time, even if they are not permitted to change at all in that time. Since actual events are at definite places in spacetime (once they exist), the longest they may be said to endure is for the temporal aspect of their space-time region. If our initial events are separated by finite time intervals, then the events themselves do not endure from one event to the next. The only particulars that so far are certainly known to endure are the propensity fields themselves. They endure because their source and realisation events are separated in time, and, because the second event could have occurred earlier, the propensity for its occurring is distributed over all the intervening possible times. Considered as a particular thing, the whole propensity field therefore endures over the finite time interval between the events. Admittedly, this endurance of propensity fields is not entirely conventional, for they extend `with one span' over temporal as well as spatial intervals, rather than being a real succession of spatial fields at successive times. It of course appears to us as if they move successively and continuously through different spatial regions between the events, but this does not mean that there is a continuous succession of actual entities, as we are really only looking at potentiality or propensity fields. It is a grave mistake to think that because something can occur at any time between two actual events, then something actually is occurring at those times: we must not confuse actualities and possibilities!

Since single propensity fields do endure, at least for a while, they can be regarded as the most basic continuants in that they never change so long as they continue to exist, and hence must remain the same even under the most technical and exacting sense of identity. Therefore we define unchanging continuant as a `separable propensity field.' They are unchanging, because they endure unchanging for their short while between two successive actual events. They can be viewed as `brittle' or `precarious' continuants, in that they cannot change in any way without becoming different continuant(s), yet while they do endure, they stay exactly the same, even staying at the same places in space-time.

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Note that although they are unchanging continuants, they do not prohibit natural change: only when they do lead to changes, they must mutate into something different, they may still appear to change for us, if we change, for example, by moving our place of view during the time between two actual events for the continuant being observed, and unchanging continuants in nature will typically only last for some small fraction of a second, the time between successive molecular collisions in typical solids, liquids, and gases.

The powers of any entity are what it is capable of doing and how it is capable of interacting. The ascription of powers is typically, adapting a definition of Harré and Madden (1975) (see also Harré 1970a), of the

``Object S has the dispositional power P to do action A''

If and only if

``if S is in some circumstance C, then there will be a non-zero likelihood of S doing A, in virtue of the constitution of S''.

In general, C will depend on P and the kind of action A.

Here, the `circumstance C' is usually defined by multiple spatial relations to other objects, and the `action A' can either be a change in S itself or an interaction with other objects. The phrase `in virtue of the constitution of S' is designed to exclude `changes' to certain properties of S that are changes in purely external relations that may come about completely independently of whatever S is actually like. The powers of a propensity field are given entirely by the spatiotemporal distribution of propensity within the field, along with the measure or description of the nature of the propensities at each place in the field. For, given the form of the field and the descriptions of its propensities, then one can predict exactly how the field is likely to interact with other fields in any given situation. This is because the `circumstances' are just the degrees of overlapping with other fields, and the actions that are possible in those circumstances are just those events to which the propensities are directed.

Matter and Form

We are now in the position of being able to identify the matter and form of the continuants defined above. Since an `unchanging continuant' has been defined as a single potentiality field, the powers of that continuant, what it is capable of doing, must be completely given by the extensive form of that field. This form for any continuant may therefore be called its substantial form, and for an unchanging continuant is again strictly unchanging. A continuant retains exactly the same powers as long as it lasts. This substantial form can be regarded as a predicate qualifying `propensity-as-such', as it is propensity (as such) which has that form. Propensity, therefore, can be regarded as the underlying `substance' or `matter' of all enduring continuants, which are therefore `forms of propensity'. `Propensity' is thus the logical subject - `that which is not predicated of something else'- and the substantial form is a predicate qualifying this subject. Traditionally, following Aristotle, this underlying subject is called the matter out of which natural things are constituted. I will not be using this term, as today it leads too readily to the concept of `material substance' of Boyle, Locke and Newton. As I wish to have a concept of substance which is to some extent independent of classical physics, the term `matter' will not be used.

In the Thomist traditions, there is an ultimate subject defined as the `pure capacity to receive determination', and called `pure potency', `primary potency', or even `prime matter'. It is thus rather more abstract than the propensities of this paper, which are always propensities for specific events and are thus to some extent already determinate even if not localised in space or time. The Thomist concept of `pure potency' or `pure capacity to receive determination' takes only the `possibility' component of the logical analysis of section 3, and is therefore a somewhat limited abstraction. Perhaps it is even a self-contradictory one, for is not to call it `pure potency' to give it some determination? There have been doubts whether such a concept is intelligible, but fortunately it is not needed for the present enterprise. We need only the concept of `propensity' or `power', as we only want to have a concept of the logical subject or substance of particular things.

Individuals

Since an unchanging continuant has constant powers so long as it lasts, it is that respect similar to the `Parmenidean Individuals' of Rom Harré (1970b). According to Harré, `Parmenidean individuals' are the ultimate individuals in nature at whatever level of microscopic analysis that may turn out to be, so the scientist does not have recourse to the internal arrangement of its parts to explain the powers of such an individual. It used to be thought, for example, that atoms were Parmenidean individuals, then (later) protons and electrons. The most likely present-day candidates are quarks, leptons and field quanta such as gluons and photons. The arrangement of their parts is not needed, because they are the ultimate individuals, and their internal constitution is not separate from their powers. Since they have no separable constituents, their nature must be identical with the particular form of all their powers. That is, to completely specify the powers of a Parmenidean individual is to completely specify its nature, its real constitution, and vice versa. This is in contrast to what Harré calls an `Aristotelean individual', which is a complex individual whose powers are explained by means of the dispositions (i.e. powers and arrangements) of its parts. Harré's Parmenidean individuals, however, endure indefinitely, and ``cannot be altered, being the bearers of numerical identity [they] cannot be transformed'', whereas the `continuants', as being conceived in the present inquiry, do not necessarily last indefinitely, only at least for a while.

The process derivation of `continuants' has the feature that in it we can see more clearly how the nature of a continuant (as a propensity field) can be identical with the `particular form of

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all its powers'. This is because, as was seen just above, all the powers of a propensity field are given by its `substantial form': the form of the field as an extensive distribution of propensity. This is in broad agreement with Ducasse's account (1964) of how a substant is related to its capacities. He argues that contrary to what the etymology of `substant' may suggest, the relation between a substant and its capacities it `has' is not analogous to the relation between, for example, a table and the objects it `stands under' and `supports'. Rather, the relation between a substant and its capacities is analogous to that which obtains between, for instance... an automobile and its parts; or a living body and its organs; or more generally between any whole and its parts.

Now, on the present account, a propensity field is a single whole particular thing, and has various possibilities for actualising contained within its extent because it extends and endures (by definition) over all the places possible. One can regard the relation between a propensity field and the places possible within it, or equivalently between a continuant and the interactions possible for it, as therefore just the relation between a unitary whole and the parts into which it may possibly (not actually!) be divided. One important consequence of this account of the continuant as a `whole' with respect to its powers as `parts' means that continuants cannot ever be properly conceived apart from their powers. Thus there never exists any separable, pure or `naked' substance. The only qualification I would give to Ducasse's account is to note that the actings of a continuant are most often interactions with other continuants, so that an account of a continuant's powers - what it is capable of doing and how it is capable of interacting - must make some reference to the condition of the other continuants with which it reciprocally interacts, and not depend only upon its own substantial form.

Changeable Continuants

So far I have defined only particular unchanging continuants, as particular propensity fields. What about changeable continuants: continuants which can endure through certain changes to themselves but keeping the same powers and properties etc.? Since under a strict sense of identity, nothing can itself change or move in any way, and still remain the same particular, it will be necessary to relax this strictest sense of identity if a sense of `continued identity' is to be obtained. We want now a sense under which one continuant can undergo interactions and shift around, and not only remain unchanging between some pair of events. Perhaps the most obvious relaxation is to allow the same substantial form over different places, so that the same continuant can at least move, as a whole, to extend over a different region of space and time. There is hence a sense of continued identity which treats two `unchanging continuants' as in fact the adjacent and successive stages of the same `changeable continuant' when there is some event over which the two `unchanging continuants', as propensity fields, are extensively continuous with each other. This event would then be the product of the earlier continuant and the cause of the later one. These two continuants have the same `substantial form' even though they do not extend over the same sets of places.

That is, for a changeable continuant to have continued identity, there must be a spatio-temporal continuity of the same substantial form. A changeable, enduring continuant therefore retains the same substantial form and the full possession of all its powers through any changes or interactions it may pass, so long as it lasts. The above conditions do not imply that even a changeable continuant must last forever: there can be sufficiently radical events in which no outcoming continuant has all the powers that once constituted one of the ingoing continuants. There can be changes in which not all the powers of a continuant are preserved through the change. Such changes could be called `substantial changes' because some continuant did not survive. Changes in which a wholly new continuant is formed can also be called substantial changes. Generation and decay events would be examples of substantial change, provided that what was generated or decayed was a single continuant, not merely an aggregate or arrangement of continuants. An example is the decay of a neutron, which in free space after about 12 minutes decays into separate proton, electron and neutrino fields, where none of the outgoing continuants has all the powers that the neutron once had [1] Most of the other interactions of the neutron such as collisions and refractions etc. do preserve that continuant, as there is a continuity of its substantial form and of its powers.

On Real Essences

Since the `substantial form' of a continuant is that on which all its powers depend, it may be called the `real essence' of that continuant. The `real essence' is defined by Locke (1706, Bk. 3, ch. 3, § 15) as `the internal, but generally (in substances) unknown, constitution, whereon their discoverable qualities [2] depend'. They may often have been unknown, but that does not mean that they are unknowable. I argue that the `real essences' of continuants, the `substantial forms' of continuants as propensity fields, are in principle quite knowable, especially as many fields can be very easily described mathematically. As Copi (1954) has pointed out, `it must be admitted that the doctrine of the unknowability of real essences was not an unreasonable doctrine to draw from the relatively undeveloped state of science in Locke's day', drawing attention to Locke's description of the then sorry state of chemistry (Locke, 1706, Bk. 3, ch. 6, § 8). It is, however, the real essences of things which science seeks to discover, and the sciences have made considerable progress since Locke's day.

It should always be remembered that these `real essences' are always the real essences of particular things. While we can intellectually distinguish the idea of the essence or form of a particular from the idea of that particular thing, that does not mean that the essence or form actually exists apart from that particular object in the world. The real essence is present only so long as the object continues to exist. They are not the `essences'

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of the medieval neo-Aristoteleanism heavily tinged with neo-Platonism, of which a certain number were supposed, `according to which all natural things are made and wherein they do exactly every one of them partake, and so become this or that species', as (Locke, 1706, Bk. 3, ch. 6, § 30) described the notion. The idea in the present enquiry is not of any such `natural essences' apart from particulars, but of the (essential) natures of particulars. We want to describe the nature which includes what a particular thing is, the principle of any changes it may go through, and that by which it may be intelligible to us.

Quantum Substances?

One feature of the present account of substances is that they are not necessarily located in small volumes of space, as, for example, the corpuscles or `particles' of classical physics would be. The propensity fields that have been defined do not even have any special `centre' distinguishable from all the other places in the field. They have no centre which could be regarded as the `true substance', so that the surrounding field could be regarded as just the `sphere of influence' of the central substance. This was Boscovich's conception, and it slowly percolated into physics, resulting in the `dynamic matter' of the mid-nineteenth century. This view is best summarized by the aphorism ``No matter without force, no force without matter''. Our propensity fields, though, have no special continuing center: the only `point source' which could perhaps be identified is the source event, which must have a definite location in space and time. The field is therefore only localized very briefly, if at all, at times just after this source event. The `continuants' we define are thus occasionally, but never necessarily, strongly localized. For most of the time they have significant spatial extensions.

Substances with this nature are particularly relevant to modern quantum physics, wherein it is found that the concept of a corpuscle with definite `extension, hardness, impenetrability, mobility, and inertia of parts' (from the beginning of Bk. III of Newton's Principia) is markedly inadequate, yet for which no philosophically adequate replacement has been hit upon. Despite the influence of a positivistic approach to metaphysics, which did not encourage people to look for new concepts, there have been a number of developments since 1926 in the interpretation of quantum physics that lead to concepts of propensities, etc., though with varying degrees of clarity.

For example, in 1926 Born realized that the quantum theory did not predict the precise state after a collision, but only the `possibility of a definite state'. The wave fields were not actual fields, but only determine the probability of the presence of quanta. As Jammer (1966, p. 286) relates, Laws of nature, as Born and Heisenberg contended from [then] on, determined not the occurrence of an event, but the probability of the occurrence. For Heisenberg, as he later explained it [3] such probability wave are ``a quantitative formulation of the concept of `dynamis', possibility, or in the later Latin version, `potentia', in Aristotle's philosophy. The concept of events not determined in a peremptory manner, but that the possibility or `tendency' for an event to take place has a kind of reality - a certain intermediate layer of reality, halfway between the massive reality of matter and the intellectual reality of the idea or the image - this concept plays a decisive role in Aristotle's philosophy. In modern quantum theory this concept takes on a new form; it is formulated quantitatively as probability and subjected to mathematically expressible laws of nature.''

Unfortunately Heisenberg does not develop this interpretation much beyond the sort of generality of the above statements, and the concept of `potentiality' remains awkwardly isolated from much of his other thought on this subject [4] The reconsiderations suggested by quantum physics have over the last sixty years for the most part come fitfully and in scattered parts of which few physicists or philosophers were fully aware in a critical sense. Heisenberg, for example, notes (1958, p. 156) that what a typical physicist of today tends to think is rather close to Aristotelean `potentia', even if unwittingly. The meanings of words such as `particle' have moreover gradually changed in these sixty years. Kaempffer (1965), for instance, after pointing out the `erosion of naive pictures of particles', goes on to suggest that the word `particle' stand for a "quantum mechanical state [a wave field], characterised by a set of quantum numbers, which is associated, in principle, with an identifiable event such as the momentum transfer in a `collision'". This conception of a wave field associated with a definite event has come a long way from the corpusclar theory, and is remarkably similar to the present account of a continuant as a propensity field which extends over the various places possible for actualising events.

The conjunction of an extensive field with some actualizing event also corresponds, I believe, to what Niels Bohr has called [5] the basic `quantum phenomenon', being an `undivided' and `closed' occurrence. It is `undivided' because between the source and realizing events is a single extensive propensity field, and not any intervening actual events which could constitute some kind of unknown connection. It is `closed' because once a place in a propensity field has become realized, the field no longer exists: its history is closed. Bohr's `complementarity' of the wave and particle aspects of the quantum phenomenon arises because although a propensity field can be regarded as propagating through space and time like an oscillating wave and as obeying a wave equation, it is in fact a single field which can produce only one actual event. This event must be at one definite place, just as a strongly-localised particle would produce. If we were not aware of the notion of a `distribution of propensity for a definite event', we would be confused because sometimes the continuant behaves like a wave, and sometimes like a particle.

The point in fact is that the continuant-field does not have a fixed spatial size. Sometimes it behaves more like a spread-out wave, and when (at other times) it interacts it behaves like a localized particle. In fact, propensity fields can have practically

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any extensive shape over the places that are possible for it, subject only to some field equation. This allows them to propagate in interesting manners around obstacles which would stop any classical atoms. They can even tunnel through barriers, as the probability for a definite interaction may be reduced but non-zero. In this way it becomes reasonable to expect the diffraction, interference and tunneling effects we know in quantum physics. It would appear overall, then, that the present conception of substance is able at least qualitatively to account for several of the features of nature that have been captured by quantum physics, and which are mysterious or impossible in classical physics. We can see how there might arise a `wave-particle complementarity', indeterminacies, objective probabilities, diffraction, interference and tunneling effects.

Propensitons

The above concept of `continuant' is very similar to Nicholas Maxwell's notion (1982,1985) of smearon or propensiton: ``Smearons'', as understood here, are hypothetical fundamental physical entities, having characteristics somewhat like the ``wave packets'' of orthodox QM in being smeared out in space like a wave function, but being unlike orthodox wave packets in having physically real nonlocal characteristics that in general exist in space and evolve in time independently of methods of preparation and measurement. What is smeared out in space is the propensity of one smearon to interact in a probabilistic, quasiparticle-like way with another smearon, should the appropriate physical (smearon) conditions to do so arise. The state vectors of QM are to be interpreted as characterising the actual physical states of smearons. The physical states of smearons evolve deterministically, in accordance with Schrödinger's time dependent equation (for elementary QM) as long as no probabilistic particle-like interactions between smearons occur. Probabilistic particle-like interactions between smearons involve changes of state which violate Schrödinger's time dependent equation even though no measurement is made.

If appropriate physical conditions arise for an unlocalized smearon, in a state F, to interact in a probabilistic way with just one of many other highly localized smearons, then, roughly speaking, the probability that the unlocalized smearon interacts with the smearon localized in dV is given by |F|2dV. (This being a microrealistic reformulation of Born's original (1926) probabilistic interpretation of wave mechanics, which appealed explicitly to measurement). Smearon QM is thus a theory that is, in the first instance, exclusively about how smearons physically evolve and interact with one another in space and time independently of preparation and measurement. Measurements are probabilistic interactions between smearons which just happen to be recorded by physicists. Stable macro-objects are the outcome of many probabilistic interactions between smearons. (Maxwell, 1982) The causal analysis of the previous sections can therefore be used to provide a philosophical justification and elaboration of the idea of smearons or propensitons, provided it is further assumed that propensitons only localise themselves intermittently.

Conclusion

In this paper, I hope to have shown that a useful concept of substance can be constructed from theories of process and causation, provided we go further along the path started by Whitehead and take seriously questions of both possibility and propensity. The reinstated concept of `continuants' means that it is not `continuants which have powers', but that is `continuants which are powers'. More precisely, they are fields of powers, where fields are spatio-temporal forms or distributions. This close connection between substances and powers was seen long ago by Locke, who wrote that `powers make a great part of our complex ideas of substance'. He also gave the even stronger characterization of power as `a principal ingredient in our complex ideas of substance'. Locke might perhaps have gone on to view a substance as a `complex of powers', but he was severely constrained as he wanted to agree with the corpuscular philosophy of his day. In that approach all substance was `material' substance and was purely actual with no trace of inherent power. However, despite these and other trends in philosophy and science to denigrate the role of powers and propensities in explanations and ontologies, it now turns out that powers have an essential role in helping us to see what it is which persists in the natural world.

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