PRINCIPIA **30**(3): 633–654 (2026) doi: 10.5007/1808-1711.2026.e110318
Published by NEL — Epistemology and Logic Research Group, Federal University of Santa Catarina (UFSC), Brazil.

THREE CONUNDRUMS OF THE QUANTUM ONTOLOGY

OLIMPIA LOMBARDI
Universidad de Buenos Aires (UBA)/CONICET, ARGENTINA
olimpiafilo@gmail.com
https://orcid.org/0000-0003-2204-7902

Abstract. For many years following the initial development of quantum mechanics, the dominant interpretative framework remained closely aligned with an instrumentalist view of the theory—quantum concepts were expected to be discussed solely in terms of measurement outcomes. However, as the influence of logical positivism waned in both science and the philosophy of science, this traditional instrumentalist stance began to lose its grip. In its place, deeper questions about the ontology implied by quantum mechanics started to emerge. What metaphysical principles are quantum systems expected to satisfy? What ontological categories are relevant in the quantum domain? These questions must be considered when addressing the fundamental structure of the quantum realm. This work adopts a realist stance, aiming to conceptually interpret quantum mechanics through a coherent ontological framework. Its primary objective is to show how standard quantum mechanics puts into crisis several philosophical principles deeply rooted in traditional metaphysics. Furthermore, it argues that, in order to conceive an ontology capable of addressing these challenges, a framework that dispenses with the notion of object and adopts an objective view of modality must be accepted.

Keywords: contextuality • omnimode determination • non-separability • independent existence • indistinguishability • ontological identity

RECEIVED: 16/09/2025 ACCEPTED: 22/09/2026 PUBLISHED: 30/10/2026

1. Introduction

For many years following the initial development of quantum mechanics, the dominant interpretative framework remained closely aligned with an instrumentalist view of the theory—quantum concepts were expected to be discussed solely in terms of measurement outcomes. However, as the influence of logical positivism waned in both science and philosophy of science, this traditional instrumentalist stance began to lose its grip. In its place, deeper questions about the ontology implied by quantum mechanics started to emerge. What metaphysical principles are quantum systems expected to satisfy? What ontological categories are relevant in the quantum domain? These questions must be considered when addressing the fundamental structure of the quantum realm.


© 2026 The author(s). Open access under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License.

This work adopts a realist stance, assuming that the aim of quantum mechanics is to describe how reality would be if the theory were true. In this sense, the perspective here adopted is in contrast with epistemic interpretations of quantum mechanics such as QBism, according to which the theory describes an agent's personal degrees of belief about the outcomes of their future experiences and, consequently, quantum probabilities are Bayesian probabilities since they quantify rational expectations, not physical propensities (Caves, Fuchs, & Schack 2002a, 2002b; see Fuchs, Mermin, & Schack 2014 for an updated presentation). From the proposed realist perspective, the quantum state is conceived not in ψ-epistemic terms—it does not represent information, knowledge, beliefs, or uncertainty about a deeper underlying state—but in terms of a ψ-ontic approach, according to which the quantum state refers to physical reality (Pusey, Barrett, & Rudolph 2012). Nevertheless, this form of realism does not lead to the so-called "wave function realism," which interprets the high-dimensional configuration space on which the wave function is defined as the real physical space (Albert 1996, 2013). In the present proposal, the quantum state is endowed with a modal reality, where modality acquires a possibilist content.

On this basis, this article aims to conceptually interpret quantum mechanics through a coherent ontological framework. Its primary objective is to show how standard quantum mechanics puts into crisis several philosophical principles deeply rooted in traditional metaphysics. Furthermore, it argues that, in order to conceive an ontology capable of addressing these challenges, a framework that dispenses with the notion of object and adopts an objective view of modality must be accepted. With this purpose, this article is organized as follows. Section 2 will revisit the challenges that quantum mechanics poses to three deeply entrenched metaphysical assumptions. Section 3 will focus on explaining how an ontology without objects can address these challenges. In Section 4, an objective, possibilist interpretation of quantum modality will be proposed for the quantum domain. The final section will offer some concluding remarks.

2. The ontological challenges of quantum mechanics

Although the three main ontological challenges posed by quantum mechanics are consequences of the formalism of the theory, they are diverse in nature and come into conflict with distinct ontological principles. These challenges arise from the following features of the theory:

- *Contextuality* prevents the simultaneous assignment of determinate values to all the properties of a quantum system. Thus, it is in conflict with the *Principle of Omnimode Determination*.

- *Non-separability* affects the independent existence of non-interacting systems. Thus, it is in tension with the *Principle of Independent Existence*.
- *Indistinguishability* is related to discerning quantum systems in the context of their statistical behavior of quantum systems. Thus, it challenges the *Principle of Identity of Indiscernibles*.

2.1. Omnimode determination

A traditional distinction in metaphysics is that between *determinables* and *determinates* (see Wilson 2022). For example, "color" is a determinable having "red," "blue," and other specific shades of color as determinates.

The determination relation differs fundamentally from other specification relations. Unlike genus-species and conjunctive relations—where a more specific property can be understood as the conjunction of a more general property and one or more independent properties—, a determinate cannot naturally be analyzed in conjunctive terms. For example, while "man" may be conceived as the conjunction of "animal" and "rational," "red" is not a conjunctive property composed of "color" and some additional property or properties. Furthermore, unlike the disjunct-disjunction relation—in which disjuncts may be dissimilar yet compatible, as in the case of "red or round"—, the determinates of a determinable are both similar and mutually incompatible. For example, "red" and "blue" are similar in that they are both colors, yet nothing can be simultaneously and uniformly both red and blue.

The *Heisenberg Principle*—also known as the Uncertainty Principle—establishes a fundamental limit on the simultaneous assignment of definite values to certain pairs of physical properties, commonly referred to as "incompatible," such as position and momentum. According to its epistemic interpretation, the principle asserts that there is a limit to the precision with which incompatible properties can be simultaneously measured: the more precisely one property is known, the less precisely the other can be determined. This epistemic reading remained widely accepted until a new result emerged within the field of physics, casting fresh light on the principle's deeper implications: Simon Kochen & Ernst Specker (1967) formulated a pivotal theorem demonstrating that the simultaneous assignment of definite values to all the properties of a quantum system leads to a logical contradiction within the framework of orthodox quantum mechanics. This result, known as the *Kochen–Specker* theorem, reveals that the assignment of definite values to quantum properties is inherently contextual.

In light of the Kochen–Specker theorem, the Heisenberg Principle assumes an ontological significance: incompatible properties correspond to determinables—physical attributes—that are not both determinate, meaning that at least one of them

has no definite value. According to the Kochen–Specker result, a quantum system necessarily possesses determinables (or observables, in physical parlance) that are not determinate. This feature of quantum mechanics stands in direct opposition to the *Principle of Omnimode Determination*, a doctrine widely upheld in modern philosophy. This principle already appears in the writings of Christian Wolff (1728), in Jacob Bernoulli's foundational work on probability theory (1713), and is reiterated throughout Immanuel Kant's lectures on metaphysics (see Kant 1902). The central idea is that, for any object, all determinables must be determinate: if the determinable "color" applies to an object, then the object must possess some specific color—such as red—regardless of its other properties and independently of our epistemic access to that color. In other words, it is metaphysically impossible for an object to possess a determinable property without also possessing some corresponding determinate: an object cannot be colored without having some particular color—red, blue, white, or otherwise. This intuitive principle is precisely what contextuality calls into question. What was traditionally taken as a metaphysical given—that an object cannot have a determinable without having some particular determinable—is no longer tenable in the quantum domain.

Perhaps it is precisely the intuitive appeal of the Principle of Omnimode Determination that accounts for its relative neglect in the history of philosophy, especially when compared to more frequently scrutinized metaphysical principles such as the Principle of the Identity of Indiscernibles. Its apparent self-evidence may have rendered it less controversial, and thus less likely to provoke sustained philosophical debate—until quantum mechanics exposed its limitations.

2.2. Independent existence

According to traditional metaphysics, objects are singly-located, they "exist in time, and cannot occupy more than one place at one time in the space to which they belong" (Russell 1911, pp.23–24). Therefore, an object can be identified by its space-time position. This idea enters the world of classical physics as the assumption that particles, located at different positions at a given time, possess an independent existence from one another, and their properties are only correlated through physical interactions whose "strength" decays with distance. When this assumption is combined with the relativistic postulate, according to which the maximum speed of any physical interaction is the speed of light, the conclusion is that correlations between particles cannot be established instantaneously.

In quantum mechanics, by contrast, physical interactions between two systems can lead to the composite system being in an *entangled* state, which introduces quantum correlations between the properties of the interacting systems. What makes this phenomenon truly remarkable is that those correlations, which persist once the in-

teraction ends, do not diminish with distance, but remain unchanged even when the original systems are very far apart. This kind of correlations is precisely that emerging in the famous Einstein–Podolsky–Rosen (EPR) experiment (Einstein, Podolsky, & Rosen 1935). Taken at face value, EPR-correlations strongly suggest the presence of non-local influences between spatially distant systems, that is, influences faster than the speed of light. However, since this idea is incompatible with special relativity, the exact nature of those quantum correlations is a subject of ongoing controversy (see Berkovitz 2016). In fact, even assuming that EPR-correlations imply a certain action-at-a-distance, it must be admitted that this action does not allow sending information at a superluminal velocity.

According to Richard Healey and Henrique Gomes (2022), quantum correlations are consequences of the holistic nature of quantum systems, understanding holism as the opposite of separability. *Separability* implies that, if a physical object is constructed by assembling its physical parts, then its physical properties are completely determined by the properties of the parts and their relationships. *Holism*, by contrast, is the characteristic of some physical objects that are not composed of physical parts, but are indivisible wholes, so that EPR-correlations are correlations between properties of a single holistic object. From the holistic perspective, it has been claimed that entanglement is evidence that the whole universe has ontological priority with respect to its parts (Schaffer 2010).

Since the terms 'locality' and 'separability' have been used in a variety of different ways, Don Howard (1989) clearly distinguishes between the corresponding concepts. Locality means that the state of a system is unaffected by events in regions of the universe so removed from the given system that no signal could connect them. The aim of the locality principle is to rule out objectionable kinds of action-at-a-distance. Separability, by contrast, is a fundamental ontological feature concerning the existence of physical systems: a non-vanishing space-time interval between two systems is a sufficient condition for their independent existence. As Howard stresses, Einstein dissatisfaction with quantum mechanics is closely related to the violation of the *Principle of Independent Existence*: "it is characteristic of [...] physical things that they are conceived of as being arranged in a space-time continuum. Further, it appears to be essential for this arrangement of the things introduced in physics that, at a specific time, these things claim an existence independent of one another insofar as these things "lie in different parts of space." Without such an assumption of the mutually independent existence (the "being-thus") of spatially distant things, an assumption which originates in everyday thought, physical thought in the sense familiar to us would not be possible." (Einstein 1948, pp.321–322; Howard's translation); "if one renounces the assumption that what is present in different parts of space has an independent, real existence, then I do not at all see what physics is supposed to describe." (Einstein in Born 1971, pp.223–224; Howard's translation).

2.3. Ontological identity

The question of ontological identity is a longstanding topic in metaphysics. A distinction is commonly made between *qualitative identity* and *numerical identity* (Noonan & Curtis 2022). Qualitative identity is a relationship between two objects that share certain properties, and is a matter of degree. Numerical identity, by contrast, is a relationship that an object has only with itself, and entails absolute qualitative identity. The present discussion will focus exclusively on numerical identity, so that the term 'identity' will be used in this specific sense throughout. It is in the context of numerical identity that different forms of identity are proposed. *Synchronic identity* is what identifies an object by distinguishing it from all the others at a certain time. *Diachronic identity* is what reidentifies an object over time.

The *Principle of Identity of Indiscernibles* (PII) states that if x and y are names of objects having exactly the same properties, then they are identical (they name the same object). The PII could work as an identity criterion because the identity relation appears in its consequent. However, in the specification of the minimal subset of properties that suffices to obtain identity, a new problem arises. In fact, three versions of the PII can be distinguished on the basis of the subset of properties considered relevant (French & Krause 2006): (i) PII_1, if two names refer to objects having all their monadic and relational properties in common, then they are identical, (ii) PII_2, if two names refer to objects having all their monadic and relational properties in common, except space-time properties, then they are identical, and (iii) PII_3, if two names refer to objects having all their monadic properties in common, then they are identical. These three versions are ordered from lowest to highest logical strength. PII_2 and PII_3, being stronger, have counterexamples in the classical (non-quantum) domain. The traditional one is the case of Black's spheres (Black 1952): two exactly equal spheres in an empty Newtonian space share all their monadic and relational properties, except the space-time ones, and yet they are two objects. PII_1, being the weakest, is the only version that is a candidate for metaphysical necessity.

Most discussions surrounding the ontological commitments of quantum mechanics center on the challenge posed by the indistinguishability of so-called "identical" particles—particles of the same kind, possessing the same state-independent properties. This challenge directly confronts the ontological category of *individual object*. The standard narrative begins by counting how many ways two particles can be distributed in two states. In classical physics, Maxwell-Boltzmann statistics yield four distinct distributions, treating the particles as distinguishable individual objects. By contrast, in quantum statistics—namely Bose–Einstein and Fermi–Dirac—a permutation of identical particles does not lead to a different distribution since particles are "indistinguishable." Although quantum theory provides formal tools to accommodate this statistical behavior, the ontological puzzle remains: why does the exchange of in-

dividual particles fail to produce a new distribution? This question strikes at the heart of how identity and individuality are understood in quantum mechanics.

Indistinguishability is often regarded as a feature that violates even the weakest version of the Principle of the Identity of Indiscernibles, thereby challenging the ontological category of individual object. As early as the 1960s, Heinz Post (1963) argued that elementary particles should not be considered individuals, but rather "non-individuals"—a view that gave rise to the so-called "Received View" of quantum indistinguishability. However, this view has been contested from various angles in an effort to rehabilitate the notion of individual object. For instance, Bas van Fraassen (1985) considers the possibility that quantum statistics is preserved by rejecting the assumption of the equiprobability of the different distributions of quantum particles on quantum states. Steven French (1989) contends that indistinguishability is a physical condition, not an ontological feature, and thus does not necessarily imply non-individuality. Moreover, the concept of weak discernibility has been proposed as sufficient to establish numerical distinction between quantum particles—even when they are indistinguishable in terms of their monadic and relational properties (Saunders 2003, Muller & Saunders 2008). In summary, despite ongoing debate and divergent interpretations, the issue of quantum indistinguishability continues to provoke intense philosophical discussions (see French & Bigaj 2024).

3. An ontology without objects

If the three ontological challenges posed by quantum mechanics undermine the category of individual object, a reasonable response is to abandon that category in favor of an ontology without objects. This radical approach has been proposed in various works (da Costa, Lombardi, & Lastiri 2013, da Costa & Lombardi 2014, Lombardi 2023, 2026); here, only its main features will be briefly outlined.

3.1. Type-properties and case-properties

The first step toward a quantum ontology without objects is to distinguish between type-properties and case-properties. This is a relevant distinction in physics: physical quantities, such as position or energy, are *type-properties*; their specific values, such as 1 meter relative to a reference point or 1 Joule relative to a reference value, respectively, are *case-properties*.

This distinction is not specific to quantum mechanics, but also applies to the classical case. For example, in the case of a billiard ball, the position $q_1 =$ "10 cm from the corner of the table" and the momentum $p_1 =$ "20 gr cm/sec with respect to the table" (in both cases, the billiard table is taken as the reference frame) are case-

properties of the type-properties $Q =$ "position of the billiard ball" and $P =$ "momentum of the billiard ball," respectively. Furthermore, those case-properties define the classical state s_1 of the billiard ball, conceived as a classical system, at a given time $t_1 : s_1 = (q_1, p_1)$.

The difference between the classical and the quantum cases does not lie in the distinction between type-properties and case-properties, but in the role played by possibility and actualization. In the classical case, at a given time, a single possible case-property corresponds to each type-property and, as a consequence, such a case-property becomes actual. For example, at time t_1, the type-property $Q =$ "position of the billiard ball" has a possible case-property, say, $q_1 =$ "10 cm from corner of the table," and this is the actual determinate position of the billiard ball at t_1. In the quantum case, by contrast, at a given time, type-properties may have many different possible case-properties, among which at most only one becomes actual. For example, in a quantum system at a given time, the type-property $S_z =$ "spin in direction z" has two possible case-properties, $s_{z1} =$ "spin up in direction z" and $s_{z2} =$ "spin down in direction z": it may be the case that one of them becomes actual; but, according to the Kochen–Specker theorem, it may also be the case that none of them become actual.

The terms 'type-property' and 'case-property' stand for 'determinable' and 'determinate,' respectively; they are used here to emphasize that the corresponding items belong to the ontological category of property. However, there is another reason why the terminology 'type-property' and 'case-property' has been preferred over the traditional terminology 'determinable' and 'determinate.' The latter, coined in the light of a classical ontology, suggests that possibility is confined to the side of the determin*able* (possible to be determinate), whereas the determinate is linked to actuality: according to the Principle of Omnimode Determination, in a particular object, a single and actual determinate corresponds to each determinable. In the quantum case, on the contrary, the determinate properties are also possible properties, which may be actualized or not. The terminology 'type-property'/'case-property' does not confine possibility to the determinable, nor is it anchored to the actual character of the determinate, which is typical of the realm of traditional metaphysics.

3.2. Non-objectual bundles of properties

The nature of objects remains a central and contentious issue in contemporary metaphysics. A key question is whether an object should be understood as a substratum that bears properties, or merely as a "bundle" of properties (see, e.g., Robinson 2021, Rettler & Bailey 2022). The idea of an object as a substratum—a carrier of properties—has a long philosophical lineage, appearing in various forms such as Aristotle's "primary substance" and Locke's "substance in general." However, following

Hume's critique of the notion of substance, many empiricist philosophers, including Bertrand Russell, Alfred Ayer, and Nelson Goodman, have rejected the postulation of a characterless substratum as metaphysically unwarranted, instead endorsing some version of bundle theory. According to this view, objects are nothing more than collections of properties; properties hold metaphysical primacy and constitute the fundamental elements of the ontology.

Some strands of metaphysical literature argue that the distinction between substratum theory and bundle theory is merely semantic. Within bundle theory, an object is conceived as the result of a "compresence relation" among properties—a construct that arguably fulfills the same explanatory role as the substance in the traditional substratum-plus-properties model. Consequently, the choice between interpreting an object as a substratum or as a bundle of properties may ultimately hinge on metaphysical preference (see Benovsky 2008). While this equivalence may hold in classical domains, quantum mechanics complicates the picture. In this context, the present proposal treats quantum systems as ontological bundles of properties, in order to avoid the challenges that quantum mechanics pose to the category of object. However, it is crucial to highlight the distinctive nature of this perspective in comparison with the traditional bundle theory.

The first point of departure involves the distinction between determinables and determinates—a distinction largely overlooked in traditional interpretations of quantum mechanics, but increasingly discussed in the metaphysics of physics (see, e.g., Calosi & Wilson 2019, 2021, Calosi & Mariani 2020, Fletcher & Taylor 2024). Traditional bundle theory assumes that an object is a bundle of determinate properties, assuming that all of its determinables are fully determinate. For example, a billiard ball is described in terms of a definite position (e.g., here), a definite shape (e.g., round), and a definite color (e.g., white). The metaphysical question then becomes whether this object is a substratum in which these determinate properties inhere, or simply the bundle of those properties. In either case, the properties involved are *actual* determinate properties. Quantum systems, however, defy this assumption. Not all determinable properties of a quantum system are determinate; therefore, the system cannot be identified with a bundle of determinate properties. In this proposal, a quantum system is instead conceived as a bundle of determinables—specifically, a bundle of type-properties, each having a collection of possible determinates, that is, case-properties. This marks a fundamental departure from traditional bundle theory and precludes subsuming quantum systems under the classical notion of object.

Second, traditional bundle theory is a theory of particular objects, which conceive objects as composed of entities from a distinct ontological category—namely, properties. In this framework, certain properties are selected to serve as the basis for synchronic and diachronic identity (see, e.g., O'Leary-Hawthorne 1995, French & Bigaj 2024). The quantum bundle view proposed here, by contrast, entirely aban-

dons the ontological category of object. Bundles of properties in this framework do not function as objects in any respect. When two bundle-systems are combined, the resulting system is itself a bundle. Since bundles are not objects, there is no principle that preserves the identity of the components across combinations: the original systems lose their identity in the resulting system precisely because they are not objects. In this sense, quantum systems are understood as *non-objectual bundles of properties*.

3.3. Facing the quantum ontological challenges

Since metaphysics is underdetermined by physics, advocating for a particular quantum ontology over competing alternatives requires demonstrating its explanatory power—specifically, how effectively it offers reasonable solutions to the interpretative problems. This subsection is devoted to show the advantages of the proposed picture for dealing with the ontological challenges of quantum mechanics: contextuality, non-separability, and indistinguishability.

3.3.1. Contextuality

In the framework of the proposed ontology of properties, quantum contextuality is expressed by stating that, given a bundle-system, not all its type-properties become actual—that is, not all acquire an actual case-property among their possible case-properties. Which type-properties actualize is a contextual matter, which depends on the specific measurement setup or observational framework.

Within any given context, one could still adhere to the classical notion of type-properties possessing definite case-properties without contradiction. In other words, the classical image of an object as a bundle of actual case-properties remains viable within a particular context. However, attempting to extend this ontological picture across all contexts—by conceiving the system as a "bundle of bundles"—runs into a fundamental obstacle: the Kochen–Specker theorem demonstrates that, in quantum systems, it is impossible to consistently assign actual case-properties to all type-properties without contradiction. As a result, the classical conception of an object as a bundle of actual case-properties fails within quantum ontology.

The Kochen–Specker theorem imposes a constraint specifically on which case-properties within a bundle can enter into actuality. However, this limitation does not undermine the proposed conception of quantum system, which is not defined as a bundle of actual case-properties (as in traditional bundle theory), but rather as a bundle of type-properties, each associated with a collection of possible case-properties. This distinction is essential: quantum bundles, in this view, do not constitute objects in the classical sense—they are non-objectual bundles.

Because the foundational elements of this ontology are properties grouped into bundles that do not qualify as objects, the Principle of Omnimode Determination—which holds for objects—is not violated but simply rendered inapplicable. Consequently, this object-free ontology remains immune to the ontological challenge posed by the Kochen–Specker theorem.

3.3.2. Non-separability

Despite ongoing debates about how best to explain EPR correlations, most arguments concerning non-separability rest on the assumption that quantum systems are individual objects, and that their subsystems are likewise objects. Accordingly, the central puzzle becomes how the properties of these objects can be instantaneously correlated, even when they are spatially separated and no longer interacting. However, when approached from an ontology of properties, this problem takes on a different character—one that aligns with Howard's interpretation of non-separability.

Recall that the ontological category of object presupposes synchronic identity and diachronic identity. Moreover, objects can form aggregates, and their countability depends on the possibility of ontologically differentiating each member of the aggregate. Thus, if two objectual systems interact to form a composite system in an entangled state, they are expected to retain their identity as distinct parts of the whole. From this perspective, EPR correlations are understood as links between the properties of these objectual subsystems, making their persistence across spatial separation and absence of interaction deeply puzzling.

By contrast, in the proposed ontology of properties, quantum systems are not objects, but rather non-objectual bundles of properties. In this framework, they do not preserve their identity when systems combine into a new bundle-system. As a result, the interpretation of EPR correlations is reformulated from the outset. The issue is no longer how distant, non-interacting objects can exhibit correlated properties. Instead, the bundle resulting from the interaction in the EPR experiment is conceived as a single, indivisible whole, not analyzable into component bundles. The correlations in question are thus established between properties of a single entity—a non-objectual bundle. From this vantage point, the mystery dissolves: correlations between properties of a single system are entirely natural, even in a classical ontology, so no mysterious harmony is required to account for them.

This perspective entails a form of holism, but without the traditional difficulties. In object-and-properties ontologies, wholes are themselves objects, and if not atomic, they can be decomposed into objectual parts distinct from the original whole. Consequently, holism within traditional frameworks faces the challenge of explaining how a composite object resists decomposition into distinct objects. This challenge vanishes within an ontology that dispenses with the category of object from the very

beginning: since the holistic entity is not an object, its lack of objectual parts is not problematic but rather a natural consequence of its own nature.

3.3.3. Indistinguishability

Although the issue of indistinguishability in quantum mechanics has sparked extensive debate, a shared assumption underlies most discussions: whether quantum systems are conceived as individuals or not, they are typically subsumed under the ontological category of object. This holds true for both the Received View—which asserts that quantum systems are non-individuals—and its critics. However, once the category of object is relinquished, the problem takes on an entirely new formulation.

While the Received View maintains that quantum systems lack individuality, some have gone further, suggesting that these systems are not even objects in any meaningful sense (Quine 1976). Yet such positions often remain metaphysically underdeveloped, offering only negative characterizations—quantum systems are said to be non-individuals or non-objects, without specifying what they are instead. In contrast, the ontology of properties proposed here offers a positive and precise metaphysical account: quantum systems are defined as non-objectual bundles of type-properties.

In an ontology without objects, indistinguishability cannot be a relationship between objects: it is primarily a relationship between properties, in particular, case-properties. More precisely, two case-properties are indistinguishable if they are properties of the same kind; for example, being "roundness" a case-property of the type-property "form", trying to distinguish between the roundness of a billiard ball and the roundness of a water drop makes no sense. Derivatively, indistinguishablity becomes a relation between type-properties when their respective case-properties are indistinguishable. Extending this derivative character, indistinguishability between bundle-systems arises when their constituent type-properties are indistinguishable.

It is important to stress that indistinguishable case-properties, indistinguishable type-properties, and indistinguishable bundle-systems are numerically distinct but not qualitatively discernible. This does not entail a violation of the Principle of the Identity of Indiscernibles, which applies specifically to objects. In the proposed ontology, indistinguishability is a relationship between properties. Therefore, the principle simply does not apply in this context. It is precisely this positive metaphysical characterization of quantum systems—as bundles of properties rather than objects—that renders the non-applicability of the principle conceptually coherent and philosophically meaningful.

4. Quantum modality

The distinction between type-properties and their possible case-properties makes it clear from the outset that modality is a significant dimension in the quantum ontology. In this section, different forms and interpretations of possibility will be examined.

4.1. Different types of possibility

Already in the Middle Ages it was recognized that true propositions fall into two groups, "necessarily true" and "contingently true." In other words, there are two "modes" in which a proposition can be true (or false): the mode of necessity and the mode of contingency—hence the term '*modality*.' At present, the term is retained to mean "pertaining to possibility and related concepts" (see Kment 2021).

A traditional classification expresses the different forms of modality: semantic, subjective, and objective modality. *Semantic modality* is relative to a logical system S and is defined in terms of derivability in the context of S: a proposition p is semantically possible relative to a logical system S *iff* $\neg p$ is not derivable from S, and it is semantically necessary relative to S *iff* it is derivable from S (Bunge 1977). *Subjective or epistemic modality* is relative to an agent and the evidence they possess, and is defined in terms of evidence and ideal reasoning: a proposition p is subjectively necessary for an agent A *iff* the evidence E_A that A possesses and ideal reasoning are sufficient to rule out $\neg p$ (Kment 2021). *Objective modality* is an ontological category, which refers to how reality may be: modal concepts apply to ontic items (objects, properties, states of affairs) independently of knowledge and agents, because objective modality is a mode of being of reality in itself.

Although logical positivism had a relatively brief lifespan, its influence permeated much of 20th-century philosophy. Its rejection of metaphysics in favor of formal logic led many philosophers of science within the analytic tradition to sidestep ontological inquiry, reframing ontological questions in linguistic or logical terms. Unsurprisingly, this stance fostered deep skepticism toward any appeal to objective modality. One of the most prominent critics of objective modality was Willard V. O. Quine (1960), who argued that if modality were to be meaningful at all, it must be grounded in the notion of analyticity—thus reducible to semantic modality. Since objective modality cannot be captured through analyticity, Quine concluded that it is ultimately unintelligible.

It was only in the final decades of the 20th century that the philosophy of science began to loosen the grip of logical positivism and its intellectual legacy. In particular, philosophers of physics turned their attention to the ontological implications of physical theories. When this inquiry focused on modality, the need to reclaim an objective understanding of possibility became increasingly evident. This development proved especially fruitful, as quantum mechanics—aside from a few subjectivist in-

terpretations such as QBism—is generally seen as introducing objective possibility into physics.

4.2. Actualism versus possibilism

The question of objective possibility is as ancient as philosophy itself. It already appeared Aristotle's treatment of future contingents. The central issue was how to assign truth values in the present to statements about future events. Aristotle maintained that while the past is fixed and determinate, the future remains open, allowing for genuine alternatives. In the generation following Aristotle, the Megarian logician Diodorus Cronus challenged this view, arguing that future contingents are illusory: the future, like the past, is fixed, and thus real possibilities do not exist (see Øhrstrøm & Hasle 2020). This classical debate reveals two fundamentally different conceptions of modality.

Actualism is the position according to which everything that exists is actual. In other words, actualism denies any kind of existence beyond actuality: to be is to exist, and to exist is to be actual (see Menzel 2021). This was precisely the position of Diodorus Cronus; in Cicero's words, "Diodorus defines the possible as that which either is or will be" (quoted in Kneale & Kneale 1962, p.117). According to Diodorus, what actually happens is all that may happen. Therefore, any claim about possibility must be reduced to a claim about actuality. For Arthur Prior, Diodorus "seems to have been an ancient Greek W.V. Quine, who regarded the Aristotelian logic of possibility and necessity with some skepticism, but offered nevertheless some «harmless» senses that might be attached to modal words" (Prior 1967, p.16). This actualist view survived through the centuries until contemporary times; for instance, for Bertrand Russell 'possible' means 'sometimes,' 'necessary' means 'always,' and 'impossible' means 'never' (Russell 1919, p.165). In other words, for actualists, the categories of actuality and possibility are coextensive: possibilities that never actualize do not exist; thus, possibility must be reduced to actuality (for a criticism to the reductive accounts of modality, see Bueno & Shalkowski 2015).

Possibilism is the denial of actualism. It is the thesis that there are ontic items (things, properties, events, facts) that are not actual. This conception is exemplified in Philo of Megara, for whom possibility is an intrinsic capability of propositions of being or not being true. In Boethius words, for Philo, "possible is that which is capable of being true by the proposition's own nature" (Boethius 1880, 2, II 234). In his dispute with Diodorus, the Stoic philosopher Chrysippus also adopts a possibilist position when he maintains that "even though something is not true and may never be true, it may nevertheless be possible" (quoted in Gould 1970, pp.77–78); so, he defines possible as "that which is not prevented by anything from happening even if it does not happen." (quoted in Bunge 1977, p.172). These quotes show that, for

possibilists, possibility is an irreducible ontological category: reality unfolds in two domains, the domain of possibility and the domain of actuality.

The debate actualism versus possibilism is still alive in present-day metaphysics, but in general it is centered on the possible existence of *possibilia*, that is, non-actual possible *objects*—such as the planet Vulcan and the literary character Sherlock Holmes (see Yagisawa 2023). This discussion is uninteresting in physics, where it is necessary to be able to describe possible states of affairs that become real when certain conditions hold. Therefore, in order to be applied to physics, possibilism must be understood as admitting that some possibilities may never become actual, but some others enter the realm of actuality while remaining possible. In this sense, the notion of possibilist possibility is closer to the Aristotelian idea of *potentia* than to the way possibility is treated in many contemporary metaphysical debates.

One of the most recent expressions of actualism in the philosophy of science is Humeanism about laws of nature, according to which laws are just patterns within the mosaic of actual events. This view is rooted in David Lewis's notion of Humean supervenience, described as "the doctrine that all there is to the world is a vast mosaic of local matters of particular fact, just one little thing and then another" (Lewis 1986a, p.ix). According to Lewis (1994), among all deductive systems that accurately describe the Humean mosaic, the "best system" is the one that strikes the optimal balance between simplicity, strength, and fit. A natural law, on this account, is simply a theorem of that best system (for criticisms, see Maudlin 2007). Within this framework, there is no ontological space for non-actualized possibilities—only the actual mosaic is granted metaphysical significance.

Despite the strong influence of actualism in contemporary philosophy of science (see, e.g., Hoefer 2019), a critical question remains: does this doctrine align with how physicists themselves conceive of physical laws? The answer appears to be negative. A notion of objective possibility—one that cannot be reduced to mere actuality—pervades the discourse of physics. When physicists declare the impossibility of superluminal signals, they are not simply asserting their de facto non-existence; rather, they are claiming that such signals are incompatible with the structure of reality as described by relativistic laws. Moreover, physical possibility does not entail future actuality. For a possible event to occur, specific enabling conditions must be met; otherwise, the event may remain perpetually non-actualized. A classic example from statistical mechanics illustrates this situation: it is physically possible for all the molecules of a gas in a container to spontaneously cluster in one corner, yet this may never happen throughout the entire history of the universe. From the standpoint of physics, the transition from possibility to actuality resembles the Aristotelian distinction between potency and act far more than it reflects the actualist framework dominant in much of contemporary philosophy of science. Physics thus seems to operate with a richer modal landscape—one in which objective possibilities play a substantive role, inde-

pendent of their actualization.

On the basis of the above arguments, it is reasonable to combine the ontological priority of properties with an *objective possibilist possibility*. From this perspective, the state of a quantum system embodies *propensities*, that is, possibilist possibilities. More precisely, given a bundle-system, its state encodes the ontological propensity to actualization for all the case-properties of all the type-properties belonging to the bundle.

At this point, it is important to emphasize that probability equal to zero does not mean impossibility. Given a case-property a of the type-property A, a is a possible property even if the system's state assigns probability zero to a. The fact that a is a case-property of A is empirically manifested by the fact that the system may have an infinite number of states that do not assign probability zero to the case-property a and in which a may become an actual property. Or, put differently: if a were really an impossible property, it would not be a case-property of the type-property A, and this would physically mean that, for this type-property A, in absolutely no state would case-property a be observed—become actual. It is worth recalling that the fact that probability zero does not mean impossibility is not a peculiarity of quantum mechanics: for example, in classical statistical mechanics, there are states with Lebesgue measure equal to zero which are not impossible according to the laws of classical mechanics: this issue has been discussed in the foundations of statistical mechanics at least since the famous book of Richard Tolman (1938).

4.3. Quantum indeterminacy

In Latin, the word '*determinatio*' means boundary, limit. It enters philosophy as 'determinacy' to design the feature of what is fully defined and, therefore, can be characterized in an unequivocal way; 'indeterminacy' refers to the absence of determinacy.

Under the influence of logical positivism, the traditional philosophy of the 20th century conceived indeterminacy as a linguistic or epistemic concept: language is not precise enough to capture reality, or human knowledge is inherently limited. Therefore, the very idea of metaphysical indeterminacy, as indeterminacy in the world, is incoherent or unintelligible (see, e.g., Russell 1923, Dummett 1975, Evans 1978, Salmon 1981, Lewis 1986b). It was only in recent decades that the idea of *metaphysical indeterminacy* began to be rehabilitated, with several authors arguing for its philosophical relevance (see Torza 2023 for an overview).

Although different approaches to metaphysical indeterminacy have been proposed, here the focus will be the *determinable-based approach* developed by Jessica Wilson (2013, 2016). According to this perspective, metaphysical indeterminacy involves states of affairs in which an object has a determinable property, but *not a unique* determinate of that determinable. Therefore, metaphysical indeterminacy can

arise for two reasons: because the considered determinable has no determinate, or because it has more than one determinate. Wilson (2013) calls the first case "*gappy indeterminacy*" and the second case "*glutty indeterminacy*."

Different situations have been presented as cases of metaphysical indeterminacy, for example, objects with fuzzy boundaries like clouds, the openness of future, the phenomenon of iridescence, a borderline-bald man, among others. Nevertheless, there is no consensus about what constitutes a legitimate case of metaphysical indeterminacy. In fact, it is always possible to argue that those cases can be interpreted as involving merely linguistic or epistemic vagueness. By contrast, quantum mechanics seems to provide a source of examples of genuine metaphysical indeterminacy, which thus becomes *quantum metaphysical indeterminacy* (Calosi & Wilson 2019).

The determinable based approach to metaphysical indeterminacy was applied to the quantum domain by several authors (e.g., Bokulich 2014, Wolff 2015, Calosi & Wilson 2019, 2021, Mariani & Torrengo 2021, Schroeren 2021, Mariani 2022). After analyzing quantum metaphysical indeterminacy in Relational Quantum Mechanics (Calosi & Mariani 2020), Claudio Calosi (2022) presents the first investigation of the matter in the context of the Modal-Hamiltonian Interpretation of quantum mechanics (Lombardi & Castagnino 2008, Lombardi 2026), which adopts an ontology of properties and an objective possibilist interpretation of possibility.

On the basis of the terminology 'case-properties'/'type-properties,' Calosi stresses that, in any bundle-system, there are always certain type-properties with no corresponding actual case-property: in the determinable/determinate language of the determinable-based approach to metaphysical indeterminacy, in any bundle there are always certain determinable properties with no determinate property, which leads to a clear case of gappy indeterminacy. In an ontology of systems as non-objectual bundles of properties, this is a theoretical result derived from the Kochen–Specker theorem.

Finally, Calosi correctly stresses that the—gappy—indeterminacy in the Modal-Hamiltonian ontology is not eliminable. According to the author, this is an important conclusion because it provides a challenge to an argument due to David Glick (2017, 2022), according to which realist interpretations of quantum mechanics do not feature fundamental indeterminacy, and that derivative indeterminacy is eliminable. Glick focuses only on Bohmian Mechanics, Spontaneous Collapse Theory, and Many Worlds Interpretation. However, "there is no reason to limit oneself to those realist interpretations. Indeed, Modal Interpretations are explicitly realistic interpretations [...] that seem to challenge Glick's argument. They offer an example (at least some of them) of a realist interpretation of quantum mechanics where indeterminacy is fundamental." (Calosi 2022, p.183).

Summing up, Calosi concludes that the Modal-Hamiltonian ontology of properties provides a significant example of an interpretation of standard quantum mechan-

ics that involves an ineliminable quantum metaphysical indeterminacy. He stresses that this is crucial for, at least, two reasons: "First, it advances the debate on quantum ontology by showing precisely how and why indeterminacy arises in a quantum world [...]. Second, it offers a naturalistic example of genuine metaphysical indeterminacy, an example coming from our best physics." (Calosi 2022, p.183).

5. Concluding remarks

From its earliest formulations, it was clear to physicists and philosophers of science that quantum mechanics challenged well-entrenched basic assumptions of traditional metaphysics. The ontological problems raised by the theory do not concern what types of objects quantum systems are, but rather what ontological categories structure quantum reality. This paper has attempted to show that a modal ontology of properties, devoid of objects, provides conceptual intelligibility to the peculiar quantum features. From this perspective, quantum systems are not objects in the philosophical sense of the term, but rather non-objectual quantum systems. Furthermore, ontology unfolds into two domains: possibility and actuality. The quantum state encodes an objective possibility that is objective—not reducible to epistemic elements—and possibilist—not reducible to actuality. In turn, the modality inherent in this vision leads to a quantum metaphysical indeterminacy that is fundamental and unavoidable.

A central problem that this approach must address is that of the language to formally express the structure of this ontology. In fact, the languages of the vast majority of logical systems, including set theory, include individual variables to designate objects. One possible solution is provided by *quasi-set theory* as proposed by Décio Krause (see, e.g., Krause 1992, da Costa & Krause 1999): although it was originally devised to provide a formalism for indiscernible quantum objects, due to its formal character it can be adapted to deal with aggregates of items that do not belong to the ontological category of object but to that of property, so that bundles turn out to be represented by quasi-sets of properties (see Holik, Jorge, Krause, & Lombardi 2022). More recently, Krause & Juan Pablo Jorge (2025) realized that the theory of quasi-sets can be further detached from its original intended interpretation, tied to the existence of *Urelemente*, and proposed a new quasi-set theory that is is "pure" in the sense that all there is are quasi-sets (Krause & Jorge 2026). A set theory of these characteristics fits in a natural way to an ontology of properties devoid of objects (Krause, Jorge, & Lombardi 2026). The natural continuation of this formal work consists in introducing modality in the formalism; but this is still a general idea in the framework of a project under construction.

References

Albert, D. Z. 1996. Elementary quantum metaphysics. In: J.T. Cushing; A. Fine; S. Goldstein (eds.), *Bohmian Mechanics and Quantum Theory: An Appraisal* p.277–284. Boston Studies in the Philosophy of Science, v.184. Dordrecht: Springer.

Albert, D. Z. 2013. Wave function realism. In: A. Ney; D. Z. Albert, *The Wave Function: Essays on the Metaphysics of Quantum Mechanics* p.52–57. Oxford: Oxford University Press.

Benovsky, J. 2008. The bundle theory and the substratum theory: deadly enemies or twin brothers?. *Philosophical Studies* 141: 175–190.

Berkovitz, J. 2016. Action at a distance in quantum mechanics. In: E. N. Zalta (ed.), *Stanford Encyclopedia of Philosophy* Spring 2016 Edition.
https://plato.stanford.edu/archives/spr2016/entries/qm-action-distance/. Access 15.09.2025.

Bernoulli, J. 1713. *Ars Conjectandi, Opus Posthumum. Accedit Tractatus de Seriebus Infinitis, et Epistola Gallice Scripta de Ludo Pilae Reticularis*. Basel: Thurneysen.

Black, M. 1952. The identity of indiscernibles. *Mind* LXI: 153–164.

Boethius. 1880. *Commentary on Aristotle's 'On Interpretation'*. 2nd edition, C. Meiser (ed.). Leipzig: Teubner.

Bokulich, A. 2014. Metaphysical indeterminacy, properties, and quantum theory. *Res Philosophica* 91: 449–475.

Born, M. (ed.). 1971. *The Born–Einstein Letters*. New York: Walker.

Bueno, O.; Shalkowski, S. A. 2015. Modalism and theoretical virtues: toward an epistemology of modality. *Philosophical Studies* 172: 671–689.

Bunge, M. 1977. *Treatise on Basic Philosophy*, V.3: Ontology I. Dordrecht-Boston: Reidel Publishing Company.

Calosi, C. 2022. Quantum modal indeterminacy. *Studies in History and Philosophy of Science* 95: 177–184.

Calosi, C.; Mariani, C. 2020. Quantum relational indeterminacy. *Studies in History and Philosophy of Modern Physics* 71: 158–169.

Calosi, C.; Wilson, J. M. 2019. Quantum metaphysical indeterminacy. *Philosophical Studies* 176: 2599–2627.

Calosi, C.; Wilson, J. M. 2021. Quantum indeterminacy and the double-slit experiment. *Philosophical Studies* 178: 3291–3317.

Caves, C. M.; Fuchs, C. A.; Schack, R. 2002a. Quantum probabilities as Bayesian probabilities. *Physical Review A* 65: #022305.

Caves, C. M.; Fuchs, C. A.; Schack, R. 2002b. Unknown quantum states: The quantum de Finetti representation. *Journal of Mathematical Physics* 43: 4537–4559.

da Costa, N.; Krause, D. 1999. Set-theoretical models for quantum systems. In: M. L. dalla Chiara; R. Giuntini; F. Laudisa (eds.), *Language, Quantum, Music*, p.171–181. Dordrecht: Kluwer.

da Costa, N.; Lombardi, O. 2014. Quantum mechanics: ontology without individuals. *Foundations of Physics* 44: 1246–1257.

da Costa, N.; Lombardi, O.; Lastiri, M. 2013. A modal ontology of properties for quantum mechanics. *Synthese* 190: 3671–3693.

Dummett, M. 1975. Wang's paradox. *Synthese* 30: 201–232.

Einstein, A. 1948. Quantenmechanik und Wirklichkeit. *Dialectica* 2: 320–324.

Einstein, A.; Podolsky, B.; Rosen, N. 1935. Can quantum-mechanical description of physical reality be considered complete?. *Physical Review* 47: 777–780.

Evans, G. 1978. Can there be vague objects?. *Analysis* 38: 208.

Fletcher, S. C.; Taylor, D. E. 2024. The representation and determinable structure of quantum properties. *Synthese* 204: #44.

French, S. 1989. Identity and individuality in classical and quantum physics. *Australasian Journal of Philosophy* 67: 432–446.

French, S.; T. Bigaj, T. 2024. Identity and individuality in quantum theory. In: E. N. Zalta; Nodelman, U. (eds.), *Stanford Encyclopedia of Philosophy*. Spring 2024 Edition. https://plato.stanford.edu/archives/spr2024/entries/qt-idind/. Access 15.09.2025.

French, S.; Krause, D. 2006. *Identity in Physics a Historical, Philosophical, and Formal Analysis*. Oxford: Clarendon Press.

Fuchs, C.; Mermin, D.; Schack, R. 2014. An introduction to QBism with an application to the locality of quantum mechanics. *American Journal of Physics* 82: 749–754.

Glick, D. 2017. Against quantum indeterminacy. *Thought: Journal of Philosophy* 6: 204–213.

Glick, D. 2022. Quantum mechanics without indeterminacy. In: V. Allori (ed.), *Quantum Mechanics and Fundamentality*, p.319–335. Synthese Library, vol 460. Cham: Springer.

Gould, J. B. 1970. *The Philosophy of Chrysippus*. Albany: Suny Press.

Healey, R.; Gomes, H. 2022. Holism and nonseparability in physics. In: E. N. Zalta; U. Nodelman (eds.), *Stanford Encyclopedia of Philosophy*. Winter 2022 Edition. https://plato.stanford.edu/archives/win2022/entries/physics-holism/. Access 15.09.2025.

Holik, F.; Jorge, J. P.; Krause, D.; Lombardi, O. 2022. Quasi-set theory for a quantum ontology of properties. *Synthese* 200: #401.

Howard, D. 1989. Holism, separability and the metaphysical implications of the Bell experiments. In: J. Cushing; E. McMullin (eds.), *Philosophical Consequences of Quantum Theories: Reflections on Bell's Theorem*, p.224–253. Notre Dame: University of Notre Dame Press.

Kant, I. 1902. *Gesammelte Schriften*. Berlin: Preußischen Akademie der Wissenschaften, Bde. 1-22; Berlin: Deutschen Akademie der Wissenschaften zu Berlin (Bd. 23); Göttingen: Akademie der Wissenschaften zu Göttingen, Bde. 24, 25, 27–29.

Kment, B. 2021. Varieties of modality. In: E. N. Zalta (ed.), *Stanford Encyclopedia of Philosophy*. Spring 2021 Edition. https://plato.stanford.edu/archives/spr2021/entries/modality-varieties/. Access 15.09.2025.

Kneale, W.; Kneale, M. 1962. *The Development of Logic*. Oxford: Clarendon Press.

Kochen, S.; Specker, E. 1967. The problem of hidden variables in quantum mechanics. *Journal of Mathematics and Mechanics* 17: 59–87.

Krause, D. 1992. On a quasi-set theory. *Notre Dame Journal of Formal Logic* 33: 402–411.

Krause, D.; Jorge, J. P. 2026. Sobre una teoría 'pura' de casi-conjuntos y su aplicación a una ontología cuántica de propiedades. *Principia* 30: 533–576.

Krause, D.; Jorge, J. P.; Lombardi, O. 2026. A quasi-set theory without atoms and its application to a quantum ontology of properties. *Synthese* 207: #6.

Lewis, D. 1986a. *Philosophical Papers*. Volume II. Oxford: Oxford University Press.

Lewis, D. 1986b. *On the Plurality of Worlds*. Oxford: Blackwell.

Lewis, D. 1994. Humean supervenience debugged. *Mind* 103: 473–90.

Lombardi, O. 2023. Not individuals, nor even objects: On the ontological nature of quantum systems. In: J. Arenhart; R. Arroyo (eds.), *Non-Reflexive Logics, Non-Individuals, and the Philosophy of Quantum Mechanics. Essays in Honour of the Philosophy of Décio Krause*, p.45–77. Dordrecht: Springer-Synthese Library.

Lombardi, O. 2026. *The Modal-Hamiltonian Interpretation of Quantum Mechanics*. Oxford: Oxford University Press.

Lombardi, O.; Castagnino, M. 2008. A modal-Hamiltonian interpretation of quantum mechanics. *Studies in History and Philosophy of Modern Physics* 39: 380–443.

Mariani, C. 2022. Non-accessible mass and the ontology of GRW. *Studies in History and Philosophy of Modern Science* 91: 270–279.

Mariani, C.; Torrengo, G. 2021. The indeterminate present and the open future. *Synthese* 199: 3923–3944.

Maudlin, T. 2007. *The Metaphysics within Physics*. New York: Oxford University Press.

Menzel, C. 2021. Actualism. In: E. N. Zalta (ed.), *Stanford Encyclopedia of Philosophy*. Fall 2021 Edition.
https://plato.stanford.edu/archives/fall2021/entries/actualism/. Access 15.09.2025.

Muller, F. A.; Saunders, S. 2008. Discerning fermions. *The British Journal for the Philosophy of Science* 59: 499–548.

Noonan, H.; Curtis, B. 2022. Identity. In: E. N. Zalta; U. Nodelman (eds.), *Stanford Encyclopedia of Philosophy*. Winter 2022 Edition.
https://plato.stanford.edu/archives/win2022/entries/identity/. Access 15.09.2025.

Øhrstrøm, P.; Hasle, P. 2020. Future contingents. In: E. N. Zalta (ed.), *Stanford Encyclopedia of Philosophy*. Summer 2020 Edition.
https://plato.stanford.edu/archives/sum2021/entries/future-contingents/. Access 15.09.2025.

O'Leary-Hawthorne, J. 1995. The bundle theory of substance and the identity of indiscernibles. *Analysis* 55: 191–196.

Post, H. 1963. Individuality and physics. *The Listener* 70: 534–537.

Prior, A. 1967. *Past, Present, and Future*. Oxford: Clarendon Press.

Pusey, M. F.; Barrett, J.; Rudolph, T. 2012. On the reality of the quantum state. *Nature Physics* 8: 475–478.

Quine, W. V. O. 1976. Whither physical objects?. In: R. S. Cohen; P. Feyerabend; M. Wartofsky (eds.), *Essays in Memory of Imre Lakatos*, p.497–504. Dordrecht: Reidel.

Rettler, B.; Bailey A. M. 2022. Object. In: E. N. Zalta; U. Nodelman (eds.), *Stanford Encyclopedia of Philosophy*. Winter 2022 Edition.
https://plato.stanford.edu/archives/win2022/entries/object/. Access 15.09.2025.

Robinson, H. 2021. Substance. In: E. N. Zalta (ed.), *Stanford Encyclopedia of Philosophy*. Fall 2021 Edition.
https://plato.stanford.edu/archives/fall2021/entries/substance/. Access 15.09.2025.

Russell, B. 1911. On the relations of universals and particulars. *Proceedings of the Aristotelian Society* 12: 1–24.

Russell, B. 1919. *Introduction to Mathematical Philosophy*. London: George Allen and Unwin.

Russell, R. 1923. Vagueness. *Australasian Journal of Philosophy* 1: 84–92.

Salmon, N. 1981. *Reference and Essence*. Princeton: Princeton University Press.

Saunders, S. 2003. Physics and Leibniz's principles. In: K. Brading; E. Castellani (eds.), *Symmetries in Physics: Philosophical Reflections*, p.289–307 . Cambridge: Cambridge University

Press.
Schaffer, J. 2010. Monism: The priority of the whole. *Philosophical Review* 119: 31–76.
Schroeren, D. 2021. Quantum metaphysical indeterminacy and the ontological foundations of orthodoxy. *Studies in History and Philosophy of Science* 90: 235–246.
Tolman, R. 1938. *The Principles of Statistical Mechanics*. Oxford: Clarendon Press.
Torza, A. 2023. *Indeterminacy in the World*. Cambridge: Cambridge University Press.
van Fraassen, B. 1985. Statistical behaviour of indistinguishable particles: Problems of interpretation. In: P. Mittelstaedt; E.-W. Stachow (eds.), *Recent Developments in Quantum Logic*, p.161–187. Cologne: Mannheim.
Wilson, J. M. 2013. A determinable-based account of metaphysical indeterminacy. *Inquiry* 56: 359–385.
Wilson, J. M. 2016. Are there indeterminate states of affairs? Yes. In: E. Barnes (ed.), *Current Controversies in Metaphysics*, p.105–125. Abingdon: Routledge.
Wilson, J. M. 2022. Determinables and determinates. In: E. N. Zalta; U. Nodelman (eds.), *Stanford Encyclopedia of Philosophy*. Winter 2022 Edition.
https://plato.stanford.edu/archives/win2022/entries/determinate-determinables/. Access 15.09.2025.
Wolff, C. 1728. *Philosophia Rationalis Sive Logica*. Reprint of the 1740 edition with introduction, notes and index in (1980) by Jean École (ed.). New York: Georg Olms.
Wolff, J. 2015. Spin as a determinable. *Topoi* 34: 379–386.
Yagisawa, T. 2023. Possible objects. In: E. N. Zalta; U. Nodelman (eds.), *Stanford Encyclopedia of Philosophy*. Summer 2023 Edition.
https://plato.stanford.edu/archives/sum2023/entries/possible-objects/. Access 15.09.2025.

Acknowledgments

I would like to warmly thank my Brazilian colleagues for inviting me to participate in the *14th Principia International Symposium*, held at Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brazil, July 28 to 31, 2025.