

100 years of Born Rule

A normativist outlook on quantum rationality

Wednesday, October 21

- Afternoon
 - 15.00-15.30 **Sebastian Horvat & Stefano Osnaghi (Vienna)** *Introductory remarks*
 - 15.30-16.20 **Diana Taschetto (Utrecht)** *How to derive the Born Rule: the half-forgotten original argument*
 - 16.30-17.30 **Markus Müller (Vienna)** *Probabilistic theories and reconstructions of quantum theory*

Thursday, October 22

- Morning
 - 10.00-11.00 **Georg Schiemer (Vienna)** *How are axioms confirmed?*
 - 11.15-12.15 **Julien Murzi (Salzburg)** *Truth and paradox in context*
- Afternoon
 - 14.00-14.30 **Anton Zeilinger (Vienna)** *Opening remarks: the quantum as source for Born's rule*
 - 14.30-15.20 **Lluís Masanes (London)** *A derivation of the Born rule without assuming anything about orthonormal bases*
 - 15.40-16.30 **Časlav Brukner (Vienna)** *Quantum indefiniteness of Born probabilities*
 - 16.30-17.20 **Borivoje Dakić (Vienna)** *Born's rule and the weak law of large numbers*
- Dinner

Friday, October 23

- Morning
 - 10.00-11.00 **Hannes Leitgeb (Munich)** *From inferential meaning to truth-conditional meaning (and back)*
 - 11.15-12.15 **Luca Incurvati (Amsterdam)** *The varieties of logical expressivism*
- Afternoon
 - 14.00-14.50 **Iulian Toader (Vienna)** *Taking Carnap beyond quantum mechanics*
 - 14.50-15.40 **Richard Healey (Tucson)** *What makes Born probabilities objective*
 - 16.00-16.50 **John Dougherty (Munich)** *Why normativism?*

Abstracts

Diana Taschetto (Utrecht University)

How to derive the Born Rule: the half-forgotten original argument

Quantum mechanics is perhaps the most successful physical theory we have ever had in terms of predictive power—and it is hardly an overstatement to say that the Born rule is almost single-handedly responsible for its predictions. The task of understanding how the mathematical formalism is related to the physical world, and why probabilities arise in quantum theory, is therefore tied to the task of understanding the Born rule, its origin and its nature—but the connection does not by itself determine the arrow of explanation. The traditional assumption that the Born rule was originally postulated rather than derived, as if it were somehow handed down from heaven, has to some extent mystified the physics behind it and has thereby fixed a very definite direction of explanation in foundational discussions: it apparently follows from it that one must resolve the interpretative questions *first*, so that an understanding of the nature of the Born rule will follow. But this assumption about the Born rule amounts to a historical claim—it may be mistaken. In which case, discussion is long overdue. In this talk, I will share some of the findings of a new and very rigorous mathematical investigation of the conceptual development of quantum mechanics that has led to the identification of important facts constitutive of the Born rule which up to now have remained hidden from sight. **Such facts are not merely clues as to how the Born rule was discovered, however: they supply the very physical premises from which the rule itself can be mathematically deduced.** They reveal the *foundation* of the proposition that, in the quantum theory, probabilities are completely determined by the modulus squared of the amplitude associated to the state of the system.

For if Max Born introduced the so-called Born rule nonchalantly, in a footnote; if his interpretation of the wave function was received without any surprise by many of his contemporaries—“we never imagined it could be anything else,” Bohr said in this regard—this is for a definite reason. There were no wave functions before 1926, of course, but the rule itself had long been fixed—it is only the mathematical object representing it that changed in 1926. The rule is there, sitting in Max Planck’s 1913 *The Theory of Heat Radiation*, for anyone who cares to look.

Markus Müller (IQOQI, Vienna)

Probabilistic theories and reconstructions of quantum theory

Around 2011, several research groups completed a project that was initiated by Lucien Hardy in 2001, but that dates back much further, both conceptually and technically: to reconstruct the Hilbert space formalism of quantum theory from simple, "operational" or "information-theoretic" principles. A role model for some of this research is Einstein's derivation of the Lorentz transformations from the relativity and light principles, giving a principled and structural explanation of an ad hoc collection of equations. This lecture will not discuss the conceptual or philosophical context of this research, but it intends to give a pedagogical summary of what has been achieved on the level of mathematical physics. The first idea to understand is that both quantum theory and classical probability theory can be seen as two special cases of generalized probabilistic theories (GPTs). There is a vast

landscape of GPTs, and some of them would predict physical phenomena that are in some sense "even weirder than quantum". It now turns out that a few simple principles are enough to single out quantum theory from the landscape of GPTs (but with considerable mathematical effort!). I will summarize an example reconstruction, and sketch the larger context of this research within quantum foundations.

Georg Schiemer (University of Vienna)

How are axioms confirmed?

A central topic in the methodology of axiomatic mathematics concerns the issue of axiom choice: how do we choose the axioms as the starting points of mathematical reasoning? How can one justify the choice of an axiom candidate? On what grounds should new axioms be accepted? Finally, is the justification of new axioms structurally similar to the confirmation of hypotheses in the natural sciences? Such questions are particularly relevant in the context of set theory and other foundational fields, especially in light of the incompleteness and independence results since Gödel's work, which show that standard axiomatizations are insufficient to decide important statements. In the present talk, I will address these questions and survey different types of "regressive" strategies for axiom choice first discussed in the works of Russell, Zermelo, and Gödel. Their examples show that, quite similar to the case of hypothesis confirmation in the sciences, new axioms are often evaluated in terms of their deductive consequences.

Julien Murzi (University of Salzburg)

Truth and paradox in context

The Liar Paradox is a seemingly valid proof of any sentence whatsoever that only resorts to logical rules and to seemingly platitudinous principles about 'true'. We argue that the key for solving the paradox is to accept that the Liar derivation is valid, up to its second last step, and that it doesn't involve the proof of a contradiction. This requires assuming, apparently against all linguistic evidence, (i) that the truth predicate has an indexical element and (ii) that the Liar derivation involves a shift of context. We claim that (i) is actually uncontroversial and that a parallel with the notion of formal proof strongly suggests that (ii) should not be controversial either.

Lluís Masanes (University College, London)

A derivation of the Born rule without assuming anything about orthonormal bases

Most derivations of the Born rule assume - among many other things - that measurements are somehow related to orthonormal bases. This is essentially equivalent to assuming that measurements correspond to self-adjoint operators. However, given Gleason's theorem, it should not come as a surprise that this brings us already close to the Born rule, and there is arguably no a priori reason whatsoever to begin with this assumption. Improving upon our earlier results of [1], I will present a derivation of the Born rule which does not make this

assumption. In doing so, I will also point out some structural pitfalls that some philosophy colleagues have fallen into -- for example, modifying the Born rule implies that the partial trace loses its validity as the rule to compute local reduced quantum states.

[1] Ll. Masanes, T. D. Galley, and M. P. Müller, *The measurement postulates of quantum mechanics are operationally redundant*, Nature Communications **10**, 1361 (2019).

Hannes Leitgeb (LMU, Munich)

From inferential meaning to truth-conditional meaning (and back)

In my talk I will investigate how the inferential meaning and the truth-conditional meaning of linguistic expressions relate to each other. In particular, I will deal with how the transition from inferential meaning to truth-conditional meaning can be rationally reconstructed in the case of logical and mathematical expressions.

Luca Incurvati (University of Amsterdam)

The Varieties of Logical Expressivism

In this talk, I will provide an overview and critical assessment of three kinds of logical expressivism. The first, reminiscent of attitude expressivism in meta-ethics, holds that logic is expressive in that logical vocabulary serves to express attitudes. For instance, traditional attitude expressivism about negation, going back to the work of Frank Plumpton Ramsey, Huw Price and others, holds that 'not' expresses disbelief. The second kind of logical expressivism, reminiscent of deflationism about truth and championed by Robert Brandom, holds that logic is expressive in that logical vocabulary serves to make explicit—typically, by expressing them as contents of assertions—the commitments that are implicit in our discursive practices. For instance, content expressivism about the conditional holds that 'if' expresses as content commitment to the goodness of certain inferential moves. The third kind of logical expressivism holds that, in a sense, logic is expressive in both ways: logical vocabulary serves to make explicit commitments to expressions of attitudes.

Iulian Toader (University of Vienna)

Taking Carnap beyond quantum mechanics

I sketch an application of Carnap's Ramsification technique to quantum mechanics, then generalize it to its interpretations and reconstructions. After noting some limitations, I recast foundational debates between interpretationists and reconstructionists as metalinguistic deliberations. This suggests that such disputes dissolve into pragmatic decisions rather than substantive discoveries about physical reality.

Richard Healey (University of Arizona, Tucson)

What makes Born probabilities objective

A frequentist two-word answer: Relative frequencies.

Popper's two-word answer: Experimental propensities.

A QBist two-word answer: Nothing does.

My two word-answer: We do.

My one-paragraph answer: The objectivity of Born probabilities is not constituted by their correspondence to or representation of anything in the physical world (such as a relative frequency, or a property of an entire experimental arrangement). The objectivity of a Born probability is *instituted* by the community of physicists and others when applying quantum theory. To accept quantum theory is to adopt a practice of that community—the practice of conforming one’s opinions to two norms governing this practice. One norm governs the doxastic state of a practitioner who applies the Born Rule. The other norm circumscribes the situations for which the Born Rule may be legitimately applied.

John Dougherty (LMU, Munich)

Why normativism?

A representationalist order of explanation uses denotation relations to explain norms of inference; a normativist order of explanation uses norms of inference to explain denotation relations. Though this distinction originates in metaphysics and the philosophy of language, a number of philosophers have recently suggested that a normativist order of explanation can be fruitfully borrowed to address problems concerning the interpretation of quantum mechanics. In this talk, I try to determine whether and how these problems of quantum mechanics are related to the metaphysical issues that originally motivated the normativist order of explanation.