OXFORD QUANTUM CENTENARY CONFERENCE.

WHAT QUANTUM?

21-23 November 2025

ABSTRACTS

What Quantum? Einstein's journey

Simon Saunders
University of Oxford

Einstein's argument of 1905 for the light quantum hypothesis is one of the most celebrated in all of physics. In the Wien limit of the Planck distribution (by then experimentally well-established), Einstein argued that thermal radiation in finite volume and frequency range consists of a finite number of localised and statistically independent entities ('light quanta'). Yet photons in the Wien regime are neither statistically independent nor localised.

I focus on the former, the lack of statistical independence, and trace Einstein's oversight to his neglect of Gibbs' 1902 treatment of indistinguishable particles. The connection was missed not just by Einstein, but by historians subsequently. It was missed in Einstein's first paper on the monatomic quantum gas of 1924 (that is very well known), but also in his second paper in 1925, by a hairsbreadth. That it was missed by historians and experts in classical statistical mechanics subsequently calls for more explanation. It was missed by physicists, but for quite different reasons: under the conviction, expressed by nearly everyone writing on quantum statistics, that it is only because quantum indistinguishable particles do not have trajectories, that indistinguishability is possible. But that is demonstrably false.

I pose the counterfactual: taking on board Gibbs' proposal, the discovery of the century, as followed from the Planck distribution and experimental evidence in favour of it, using Einstein's fluctuation method, was not so much that thermal electromagnetic radiation in finite volume and finite frequency range consists of a finite number of entities (as implied by the Wien limit), but that the state space of each of those entities is finite (as implied by the Rayleigh-Jeans limit). The former was surmised by Newton and was the dominant view throughout much of the 18th century; It is the discovery of finitude, not in the number of entities of such-and-such a sort, but in the number of their states, that was truly revolutionary.

What's the matter? The path from electron diffraction to duality

Elise Crull
City College of New York

The historical trajectory from electron diffraction experiments to the acceptance of matter wave-particle duality is interesting to trace for several reasons. First, it foregrounds the crucial role in scientific progress of idea exchange among experimentalists (n.b., not *experiments*) and theorists — an aspect of quantum history often minimized to make room for heroic tales of *Knabenphysik*. Second, highlighting experimentalists makes room to reintroduce the overlooked contributions of women who, if allowed to practice science at all in this period, were usually relegated to labs or classrooms. Third, it's an interesting case study as to how and when a scientific community accepts experimental data as evidence for some new, radical feature of reality.

Bohr was not obscure!

Guido Bacciagaluppi
Utrecht University

Niels Bohr's writings on the foundations of quantum mechanics, for instance the Como lecture or his reply to Einstein, Podolsky and Rosen, have often been seen as obscure. Like other recent researchers, I believe that such criticisms are due to misunderstandings, and in this talk I shall try to present some aspects of Bohr's views on quantum mechanics in a way that may hopefully help clarify these misunderstandings surrounding them.

Locality, causality, and all that: from EPR to Bell's theorems and beyond

Eric Cavalcanti
Griffith University

The Many Faces of Quantum Contextuality

Matt Leifer
Chapman University

Quantum Contextuality, in the form of the Bell-Kochen-Specker no-go theorem, has often played second fiddle to Bell's theorem in its impact on our understanding of quantum theory. It has been accused of only applying to quantum theory, being experimentally untestable and of not telling us anything we could not already have gleaned from Bell. However, in recent years, quantum contextuality has been operationalized, generalized, and experimentally robustified, particularly in the form proposed by Spekkens, and it now arguably provides the deepest insight into the quantum-classical divide. I will explain how we got from there to here, commenting on some of the debates and controversies along the way, and describe the insights it provides into the nature of quantum phenomena such as interference, the quantum Zeno effect, anomalous weak values, quantum state distinguishability. If time permits, I will comment on its relationship to results about the nature of the quantum state.

Classical and Quantum Realities

Roger Penrose
Oxford University

Quantum machines learning quantum

Gerard Millburn
University of Sussex

The world is full of biological learning machines, and one instance of those discovered that the world is quantum. Can we build engineered learning machines to control the quantum world better than humans can? Can engineered learning machines discover new laws of nature beyond human comprehension? In this talk I will explain the physical constraints on learning machines using the principles of stochastic quantum thermodynamics. The rate of learning is determined by the energy dissipation per training epoch, linking an information theoretic quantity to a thermodynamic quantity; an analogue of Landauer's principle. At low temperatures, quantum noise, not thermal noise, determines the learning rate. This suggests new directions for engineered learning machines that minimise energy consumption based on quantum stochastic perceptrons. I will discuss how populations of learning machines, doing automated quantum experiments, giving a technological spin to Wigner's friend scenarios. Finally, I will describe how space and time can emerge as learned functions in a multi agent setting, with implications for reconciling gravity and quantum.

"In the continual whirl and din of the factory": Thermodynamics meets quantum (information) science

Nicole Yunger Halpern
Joint Center for Quantum Information and Computer Science (QuICS), University of Maryland

This year, we celebrate the one hundredth birthday of (part of) quantum theory. Last year, we celebrated the two hundredth birthday of Carnot's theorem, a formulation of the second law of thermodynamics. Thermodynamics emerged to describe large, classical systems, epitomized by the steam engine. Yet small and quantum systems exchange heat, perform work, and have temperatures. We can extend the laws of thermodynamics to such systems, using quantum information science. Quantum phenomena can enhance thermodynamic tasks such as work extraction, while thermodynamic quantities such as entropy production can signal nonclassicality. I will overview this interchange between quantum (information) science and thermodynamics. In the words of one novelist of the British Industrial Revolution, "it would do both good to see a little more of the other."

Reference: NYH, *Quantum Steampunk: The Physics of Yesterday's Tomorrow*, Johns Hopkins U. P. (2022).

Operationalism, Causality, and Quantum Theory: a mostly time symmetric perspective

Lucien Hardy
Perimeter Institute

From machine learning-based control of quantum devices to the thermodynamics of learning

Natalia Ares
University of Oxford

As devices are miniaturised to the nanoscale, fluctuations emerge as a defining factor, posing challenges for quantum device control. At the same time, they reveal the nuances of dissipation and thermalisation processes at this scale, opening opportunities to investigate thermodynamics in nanoscale systems.

I will show how advanced machine learning approaches enable efficient characterisation and control of quantum devices. Alongside enabling automated operation, these methods can reveal otherwise inaccessible device properties, offering new physical insights into performance limits and variability.

I will then explore the complementary perspective: how fluctuations can be harnessed to drive device functionality. In particular, I will describe the realisation of a nanoscale clock driven by single-electron tunnelling. Building on this concept, I will discuss how nonequilibrium phenomena enable the development of nanoscale engines and refrigerators, and how these systems provide a platform to probe the fundamental thermodynamic costs of learning and information processing.

A new argument for gravitational collapse?

Wayne Myrvold
Western University

From quantum picturalism, to education, cognition, AI, and music

Bob Coecke

Over some 20 years we have developed a diagrammatic quantum formalism, sometimes referred to as quantum picturalism [1, 2]. We showed that this formalism enabled secondary school students to perform exceptionally well on an Oxford University post-grad quantum exam [3].
In 1935 John von Neumann denounced `his own' Hilbert space based quantum formalism. Alternatives had been proposed, including by von Neumann himself, but none play a significant role in quantum theory today. Quantum picturalism on the other hand, is now widespread in quantum technology research, and in quantum foundations. Quantum picturalism follows Schrödinger's focus on composition of systems rather than von Neumann's focus on measurement.

The same formalism has been used as the basis for cognition with applications to interpretation and generalisation for AI [4, 5], and underpins the first piece of music to ever have been produced with a quantum computer [5].

[1] Bob Coecke and Aleks Kissinger (2017) Picturing Quantum Processes. Cambridge University Press.
[2] Bob Coecke and Stefano Gogioso (2022) Quantum in Pictures. Quantinuum.
[3] https://www.theguardian.com/science/2023/dec/16/physicist-bob-coecke-its-easier-to-convince-kids-than-adults-about-quantum-mechanics
[4] https://thequantuminsider.com/2024/09/18/quantinuum-unveils-first-contribution-toward-responsible-ai-uniting-power-of-its-quantum-processors-with-experimental-work-on-integrating-classical-quantum-computing/
[5] https://qspace.fqxi.org/articles/264/quanthovens-fifth

Beyond the Born rule in quantum gravity and high-energy physics

Antony Valentini
Imperial College London

After a brief overview of de Broglie-Bohm pilot-wave theory, we focus on two areas where the theory suggests that the Born rule could be unstable, yielding an observable breakdown of quantum physics. First, we consider quantum gravity, and show that in pilot-wave theory there is no Born rule at the fundamental Planck scale. In the semiclassical approximation, tiny non-Hermitian corrections render the usual Born rule unstable, an effect which could appear in Hawking radiation. Second, we consider high-energy particle physics, and show how a simple regularisation of pilot-wave theory (required at nodes of the wave function) may render the Born rule unstable at very short timescales. We end with a discussion of how the Born rule can be tested at high-energy colliders.

Shut Up and Calculate in the Everett Interpretation

David Wallace
University of Pittsburgh

Physicists and philosophers alike often talk about the measurement problem as a problem of underdetermination: we have lots of empirically equivalent interpretations, so we choose between them by appealing to their extra-empirical virtues and vices - or else we don't bother, and just shut up and calculate. But this is an illusion: the measurement problem turns on underlying disagreements in physics about what the quantum formalism is or should be and how it is applied. I identify three Views one could take of quantum theory: the Modificatory View (the formalism is irretrievably broken, can be applied only through ad hoc moves, and must be replaced); the Lab View (quantum mechanics is inherently some kind of calculus of observation, in which notions of 'information' and 'observer' are conceptually central); the Decoherent View (quantum mechanics is an always-unitary, dynamical theory; measurement is just one more interaction and an observer is just one more physical system; we should worship in the Church of the Larger Hilbert Space). As I will argue, the first two views are not at present *scientifically* viable approaches to quantum mechanics, whatever their philosophical merits. Only the Decoherent View has the resources to make sense of contemporary applications of quantum mechanics; its problems, if any, are purely philosophical.

Relational Interpretations: Why and How?

Emily Adlam
Chapman University

There are clear and compelling reasons to think that the correct interpretation of quantum mechanics should have a relational flavour, but there are also many open questions about exactly how this idea should be implemented. In this talk I will lay out the case for relational approaches to quantum mechanics, and then discuss some of the questions and challenges. In particular I will consider what quantum descriptions should be relativized to, how relationality intersects

with intersubjectivity, and what the Extended Wigner's Friend paradoxes tell us about quantum relationality.

Quantum Theory, Dynamics First

Nick Ormrod
Perimeter Institute

From Wheeler to QBism and back to Wheeler

Chris Fuchs
University of Massachusetts, Boston