Intersectional Symposium The Concept of Reality in Physics (SYRP)

lead by the Atomic Physics Division (A)

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Since the early days of quantum mechanics the debate on the epistemological consequences of the theory has never been completely finished. Nowadays we see a revival of this old discussion which began with the dispute between Albert Einstein and Niels Bohr. In particular, the compatibility of special relativity and quantum entanglement is now reconsidered in the light of more straightforward concepts than in the past. In addition, new experiments are providing new evidence for the reality of quantum entanglement. The symposium will highlight these recent developments.

Overview of Invited Talks and Sessions

(lecture room HSZ 01)

Invited Talks

SYRP 1.1	Wed	14:30–15:00	HSZ 01	**What is realism in physics? What is the price for maintaining it?** — •Anthony J. Leggett
SYRP 1.2	Wed	15:00–15:30	HSZ 01	**Testing concepts of reality with entangled photons in the laboratory and outside** — •Anton Zeilinger
SYRP 1.3	Wed	15:30–16:00	HSZ 01	**Special relativity and quantum entanglement: How compatible are they?** — •Tim Maudlin
SYRP 2.1	Wed	16:30–17:00	HSZ 01	**What can we learn from Bell's inequalities violations: the answers of Einstein and Feynman** — •Alain Aspect
SYRP 2.2	Wed	17:00–17:30	HSZ 01	**Physics and Narrative** — •David Albert
SYRP 2.3	Wed	17:30–18:00	HSZ 01	**The relativity of inertia and reality of nothing** — •Alexander Afriat
SYRP 2.4	Wed	18:00–18:30	HSZ 01	**Obtaining Information about and Controlling Quantum Particles: Quantum Engineering** — •Dieter Meschede

Sessions

SYRP 1.1–1.3	Wed	14:30–16:00	HSZ 01	**The Concept of Reality in Physics I**
SYRP 2.1–2.4	Wed	16:30–18:30	HSZ 01	**The Concept of Reality in Physics II**

SYRP 1: The Concept of Reality in Physics I

Time: Wednesday 14:30–16:00 Location: HSZ 01

Invited Talk SYRP 1.1 Wed 14:30 HSZ 01

What is realism in physics? What is the price for maintaining it? — •Anthony J. Leggett — Department of Physics, University of Illinois, Urbana, IL, USA

While the formalism of quantum mechanics, if taken seriously, appears to raise doubts about "naive realism" as applied to the physical world, a more important point (as appreciated in effect by the late John Bell) is that if in certain types of experiments the results come out as predicted by QM, then irrespective of the validity or not of the QM world view, *the experimental outcomes themselves* pose challenges to a realistic viewpoint. The relevant experiments fall into two major classes, each motivated by a classic paradox of QM:EPR on the one hand, Schrödinger's cat on the other. I will try to explore the possible meanings of "realism" in each of these contexts, and ask what price one has to pay (or may in the future have to pay, if the predictions of QM continue to be confirmed) in order to maintain some form of the concept of realism in physics.

Invited Talk SYRP 1.2 Wed 15:00 HSZ 01

Testing concepts of reality with entangled photons in the laboratory and outside — •Anton Zeilinger — Faculty of Physics, University of Vienna, Austria

In this talk, I will present some recent experiments on the foundations of quantum mechanics and discuss their implications. In tests of Bell's Inequalities over a distance of 144 km on the Canary Islands, we recently closed the Freedom of Choice Loophole[1]. There also have been new tests of quantum reality, realizing Schrödinger's idea of *steering* Wheeler's Delayed Choice, and Nonlocal Quantum Erasers. These, together with the experiments testing Leggett's Non-Local Realistic Model, hint that it is Naïve Realism which is at stake. Yet, in the talk I will also discuss other possibilities like counterfactual definiteness, retroaction, or determinism. Future fundamental experiments will certainly explore states in higher-dimensional regions of Hilbert space hitherto unexplored. Such experiments are possible with photons by employing for example modes beyond Gaussians like orbital angular momentum states and Hermite-Gaussian modes or multimode states using multiport beam splitters. A specific example is the question of mutually unbiased bases in an Hilbert space of dimension d.

[1] Proc. Natl. Acad. Sci. USA **46**, 19709-19713 (2010)

Invited Talk SYRP 1.3 Wed 15:30 HSZ 01

Special relativity and quantum entanglement: How compatible are they? — •Tim Maudlin — Department of Philosophy, Rutgers University, New Brunswick, NJ, USA

It is the entanglement of quantum systems–not issues concerning either determinism or uncertainty–that marks the strongest break between classical and quantum physics. The tension between entanglement and Relativity was the source of both Einstein's and Schrödinger's dissatisfaction with the standard understanding of quantum theory, on account of the "magical" or "spooky" effect that the measurement of one system was claimed to have on the physical condition of a distant entangled system. Bell proved that this non-locality of standard quantum theory is not eliminable: any theory capable of reproducing the standard predictions must be non-local. The import of Bell's work has even today not been universally appreciated. A full reconciliation between quantum theory and Relativity requires an exact formulation of quantum theory–including "measurement"–that makes use only of Relativistic space-time structure. The non-locality cannot be eliminated, but perhaps it can be made completely Lorentz covariant. It is worth considering whether such a full reconciliation is possible, and, if so, whether it is worth the price.

SYRP 2: The Concept of Reality in Physics II

Time: Wednesday 16:30–18:30 Location: HSZ 01

Invited Talk SYRP 2.1 Wed 16:30 HSZ 01

What can we learn from Bell's inequalities violations: the answers of Einstein and Feynman — •Alain Aspect — Institut d'Optique, Palaiseau, France

In 1935, with Podolsky and Rosen, Einstein discovered an amazing quantum situation, where particles in a pair are so strongly correlated that Schrödinger called them "entangled". By analyzing that situation, Einstein concluded that the quantum formalism had to be completed in order to be compatible with his world view, local realism. Niels Bohr immediately opposed that conclusion, and the debate lasted until the death of these two giants of physics, in the 1950's. In 1964, John Bell produced his famous inequalities which would allow experimentalists to settle the debate, and to show that local realism is untenable.

What can we conclude? Reading Einstein's argument in defense of local realism, we can find hints about what to abandon among concepts inherited from classical physics. But according to Feynman, this renouncement actually opens new possibilities. . .

Invited Talk SYRP 2.2 Wed 17:00 HSZ 01

Physics and Narrative — •David Albert — Department of Philosophy, Columbia University, New York City, NY, USA

I will discuss a simple, striking, and previously unnoticed tension between quantum-mechanical entanglement and the special theory of relativity. This new tension has nothing to do with the quantum-mechanical non-locality discovered by Bell - it arises (unlike Bell's non-locality) prior to any attempt at solving the measurement problem, in the context of the linear unitary quantum-mechanical equations of motion. I will show (in particular) that quantum-mechanical entanglement, together with the principle of relativity, entails that there can be no comprehensive account of the history of any multiple-particle quantum-mechanical system in the form of a 1-parameter assignment of instantaneous states - it will be shown (that is) how quantum-mechanical entanglement together with the equivalence of all inertial frames of reference entails that there can be no comprehensive account of the history of any such system in the form of a narrative. Some of the implications of this new tension for our understanding of the metaphysics of relativistic quantum theories will be considered.

Invited Talk SYRP 2.3 Wed 17:30 HSZ 01

The relativity of inertia and reality of nothing — •Alexander Afriat — Département de Philosophie, Université de Brest, France

We first see that the inertia of Newtonian mechanics is absolute and troublesome. General relativity can be viewed as Einstein's attempt to remedy, by making inertia relative, to matter – perhaps imperfectly though, as at least a couple of freedom degrees separate inertia from matter in his theory. I consider ways the relationist (for whom it is of course unwelcome) can try to overcome such underdetermination, dismissing it as physically meaningless, especially by insisting on the right transformation properties.

Invited Talk SYRP 2.4 Wed 18:00 HSZ 01

Obtaining Information about and Controlling Quantum Particles: Quantum Engineering — •Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Germany

Beginning with the observation of a single trapped ion in 1978, single particles have been widely used to experimentally illustrate concepts of quantum physics once considered purely abstract, e. g. quantum jumps. Since the 1990s, experimentalists have left the position of an observer and have begun to explore a new role as quantum engineers, exploiting the special properties of quantum dynamics and attempting to implement relevant processes in quantum information science. In this talk I will discuss the question how information about a simple atomic quantum system is obtained and can be used to steer it to a given state. Explicit examples include observation of atomic trajectories, quantum walks, and feedback schemes.