

## QUANTUM UNCERTAINTY – IN ALL ITS GUISES

Paul Busch

Department of Mathematics, University of York, York, UK

### ABSTRACT.

The Uncertainty Principle, conceived by W. Heisenberg in 1927, epitomises the fundamental philosophical implications of quantum mechanics and its radical departure from classical physics. For decades, there has been an air of vagueness and perhaps even mystique around its formulation and interpretation, which may have contributed to the media hype in 2012 when it was announced that the principle had been experimentally violated. In this lecture I survey precise mathematical formulations of Heisenberg’s principle in all its guises as a statement about (a) uncertainties, (b) unsharpness, (c) measurement inaccuracies, and (d) disturbance due to measurement. Recent claims about the failure of the principle are shown to be untenable and found to have arisen from the unwarranted extrapolation of classical physical intuitions about measurement inaccuracies.

## ON THE “ZOO” OF HEISENBERG UNCERTAINTIES, AND HOW TO MEASURE INCOMPATIBLE QUANTUM OBSERVABLES

Paul Busch

Department of Mathematics, University of York, York, UK

### ABSTRACT.

Developing the theme of the introductory lecture “Quantum Uncertainty – in All Its Guises”, I will give a more detailed review of the mathematical modeling of joint measurements of incompatible quantum observables, using the theory of operator measures on Hilbert spaces. I will show how the noncommutativity of observables can be overcome as an obstruction to their joint measurability by allowing for appropriate trade-offs for the relevant measurement accuracies and the degrees of necessary disturbance caused by the measurements.

Paul Busch (Biographical Sketch, 2013)

Paul Busch is Professor of Mathematical Physics at the University of York (since 2005). His research interests lie in the mathematical and conceptual foundations of quantum physics and quantum information, with a focus on the quantum theory of measurement, quantum theory and relativity, and the quantum-classical interface. He studied physics, mathematics and philosophy at the University of Cologne and received his doctorate in theoretical physics there in 1982 under the supervision of Peter Mittelstaedt. Postdoctoral research positions included periods at the University of Cologne and the Max Planck Institute for biophysical Chemistry, Göttingen. After his Habilitation in 1988 Paul Busch was University Docent and apl. Professor at the University of Cologne. He moved to the University of Hull in 1995 where he was awarded a Chair in 2002.

He has held long-term visiting positions at Florida Atlantic University (Visiting Associate Professor of Mathematics, 1986), the University of Heidelberg (Visiting Professor of Philosophy of Science, 1994), Harvard University (Research Scholar and Feodor Lynen Fellow 1994-1995) and the Perimeter Institute for Theoretical Physics (Visiting Research Professor 2005-2007).

Paul Busch has published over 100 papers and is coauthor of two monographs, *The Quantum Theory of Measurement* (Springer, 1991/1996) and *Operational Quantum Physics* (Springer, 1995/1997). He serves as Associate Editor of the journal *Foundations of Physics* and is Co-Editor of Springer’s *Fundamental Theories of Physics* monograph series. In 2009 he was elected member of L’Académie Internationale de Philosophie de Science (AIPS).

### *Selected Publications:*

*Heisenberg’s Uncertainty Principle.* With T. Heinonen, P.J. Lahti, *Physics Reports*, Vol. 452, pp. 155-176, 2007.

*Position Measurements Obeying Momentum Conservation.* With L. Loveridge, *Physical Review Letters* 106, 110406 (2011).

*Operational Quantum Physics.* With M. Grabowski, P. Lahti. (Lecture Notes in Physics Vol. 31, Springer 1995, 2nd corr. Printing 1997).

*The Quantum Theory of Measurement.* With P. Lahti, P. Mittelstaedt. (Lecture Notes in Physics, Vol. 2, Springer 1991, 2nd ed. 1996).