Introduction
(Lecture of the Quantum Information class of the Master in Quantum Science and Technology)

Géza Tóth

Theoretical Physics, University of the Basque Country (UPV/EHU), Bilbao, Spain
Donostia International Physics Center (DIPC), San Sebastián, Spain
IKERBASQUE, Basque Foundation for Science, Bilbao, Spain
Wigner Research Centre for Physics, Budapest, Hungary

UPV/EHU, Leioa
17 January, 2024

Outline

What is quantum information?

Interdisciplinary field based on

- Quantum mechanics (typically nonrelativistic)
  - Schrödinger equation, published in 1926
  - John von Neumann, E. P. Wigner
- Quantum optics,
  - Photodetection and the statistics of light, coherent states, etc., George Sudarshan, Roy J. Glauber, and Leonard Mandel, 1950's, 1960's

What is quantum information? II

- Quantum optics (continued)
  - The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber "for his contribution to the quantum **theory of optical coherence**", the other half jointly to John L. Hall and Theodor W. Hänsch "for their contributions to the development of **laser-based precision spectroscopy**, including the optical frequency comb technique."
  - The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland "for ground-breaking experimental methods that enable measuring and **manipulation of individual quantum systems**."
  - The Nobel Prize in Physics 2022 was awarded jointly to Alain Aspect, John F. Clauser and Anton Zeilinger "for experiments with **entangled photons**, establishing the violation of **Bell inequalities** and pioneering quantum information science."

What is quantum information? III

- Computer science
  - Computational complexity theory, analysis of algorithms and computability theory.
- Unlike many areas of physics, it has a constructive side.
- Very often the goal is to create quantum states of very many particles experimentally, or to make a quantum computer.
- The theory is trying to help this development.

Subfields of quantum information science

- Theory of nonlocality, Bell inequalities, 1964
- Theory of quantum entanglement, Werner, 1989
- Quantum metrology (measuring some quantity using a quantum system), many experiments from 2000
- Quantum computer, quantum algorithms (factoring primes, Shor, 1994 and search, Grover, 1996)
- Quantum communication, quantum cryptography, BB84 (1984)
- Quantum error correction (three-qubit bit flip code, Asher Peres in 1985; Shor code 1995)
- Quantum simulation (one can simulate so large quantum systems that could not fit into a classical computer)