Quantum Information with Solid-State Device

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Lecture 1

ATOMINSTITUT

Solids 4 Fun
BUILDING SOLIDS FOR FUNCTION

TU WIEN

Overview

- Administration
- Motivation
- Subjects covered in the Lecture
- History

Administration

- Goal
  get you to the actual research frontier
- Place & Time
  Fachgruppenraum, Freihaus Monday 15:00-16:30

Website & Communication

http://majer.ch/qiss
tiss
johannes.majer@tuwien.ac.at

- Literature & Further Reading

website
end of lecture

Administration

- Homework Problems

  Purpose: review the material covered in the lecture
  enter your name in the list, if you have done it
  we randomly pick somebody to explain the solution
  1 point for a entry in the list, extra point for a good presentation
  75% of the possible points for a mark 1 in the first part of the exam
  making mistakes is not a problem

- Exam

  1st part if not fulfilled with the homework problems

  read and present an actual research paper

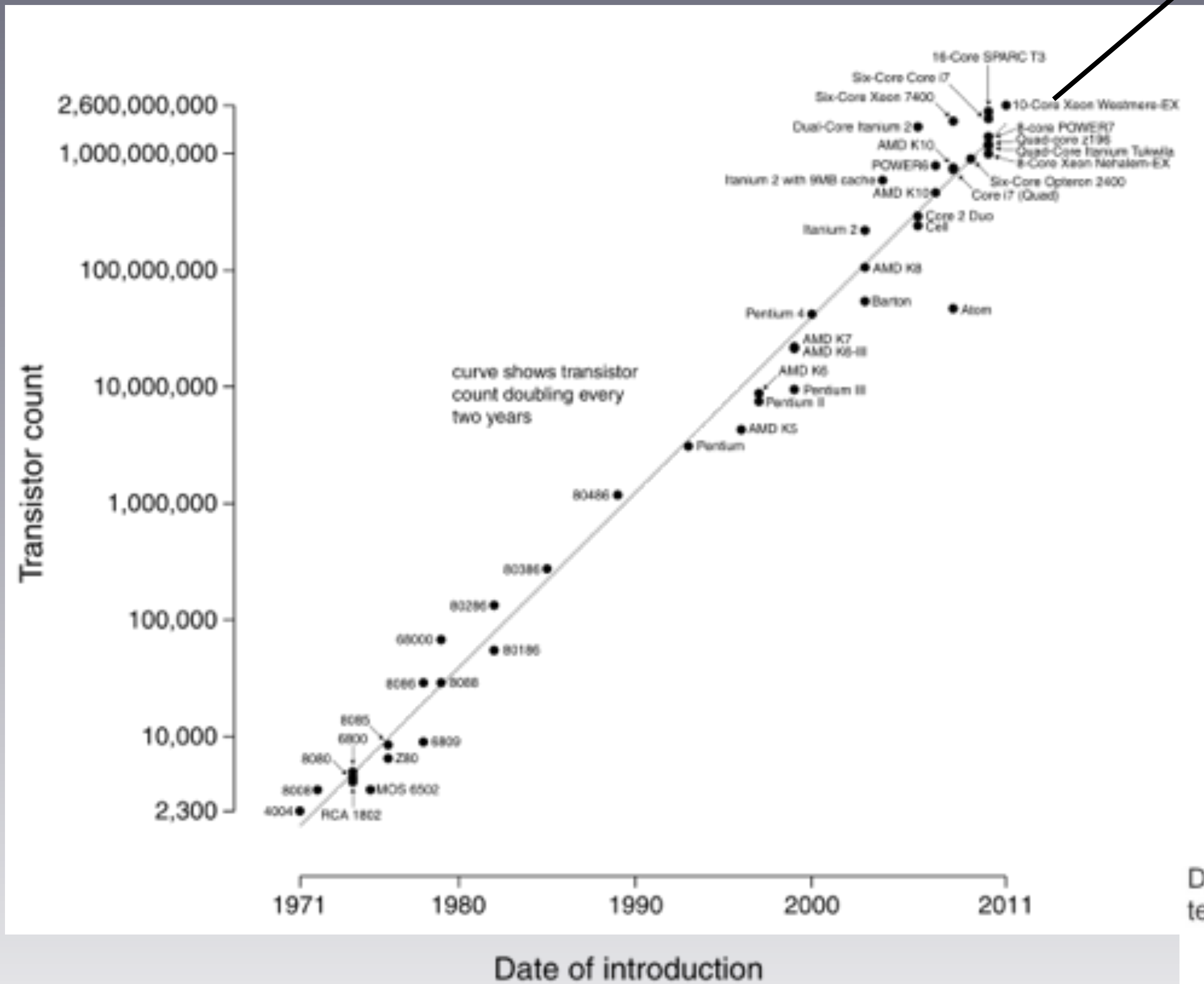
- Material

  Website:
  Slides & Handnotes
  Problem Sets & Solutions
  Extra material

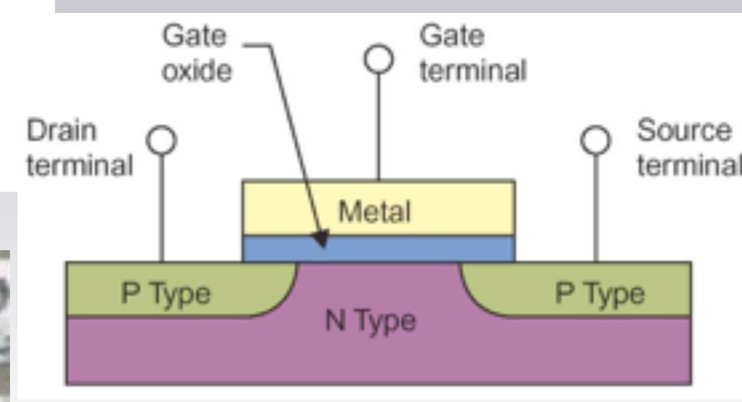
Moore's Law

quantum regime

Microprocessor Transistor Counts 1971-2011 & Moore's Law

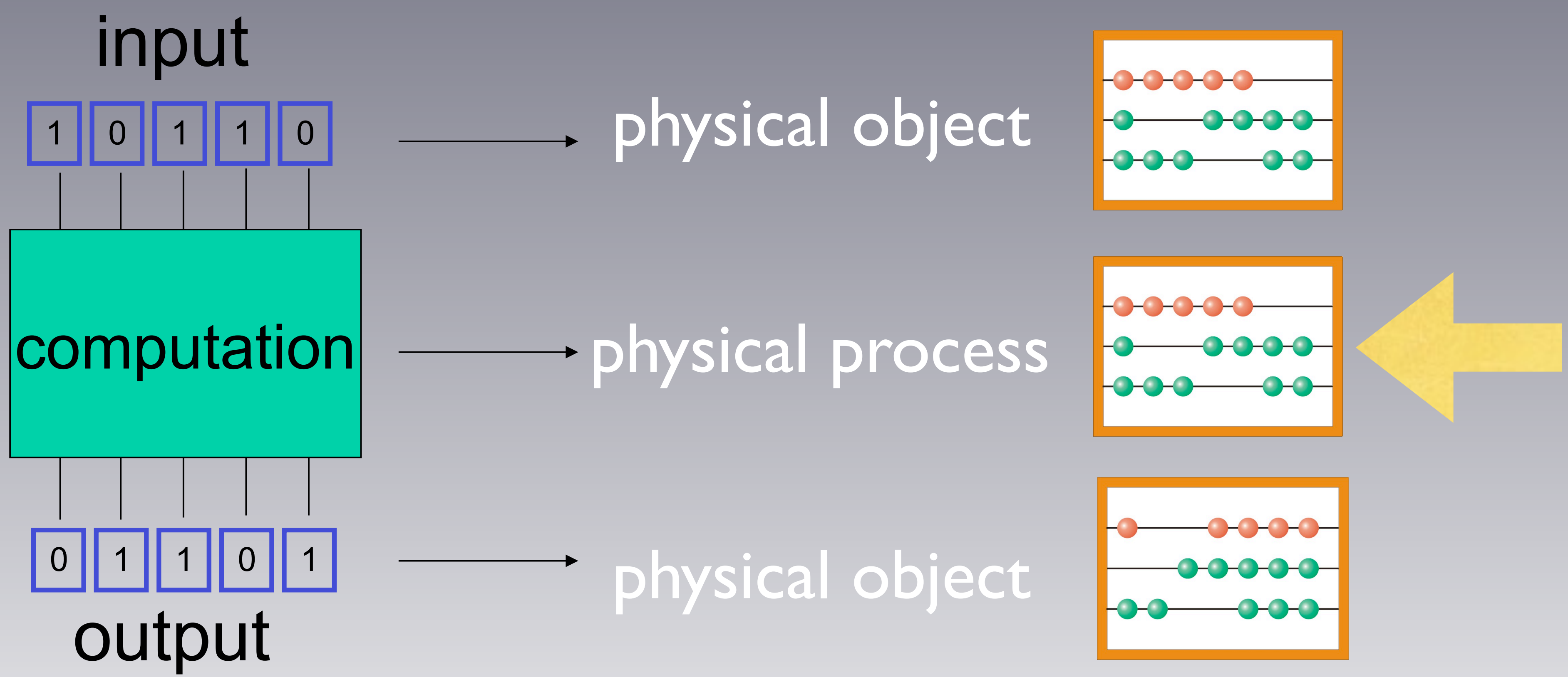


number of transistors doubles every 2 years
Gorden Moore 1965



Information & Physics

information processing
is a physical process



information is physical
Rolf Landauer

Quantum Information

the fundamental laws of physics is quantum mechanics

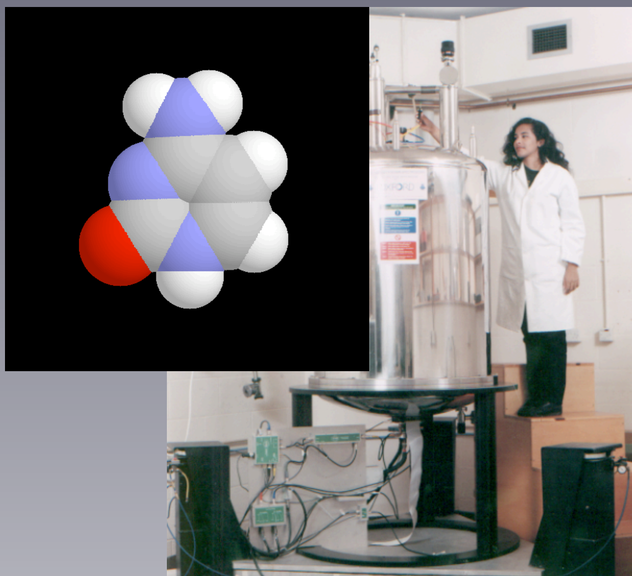
therefore the fundamental laws of information processing is quantum mechanics

David Deutsch

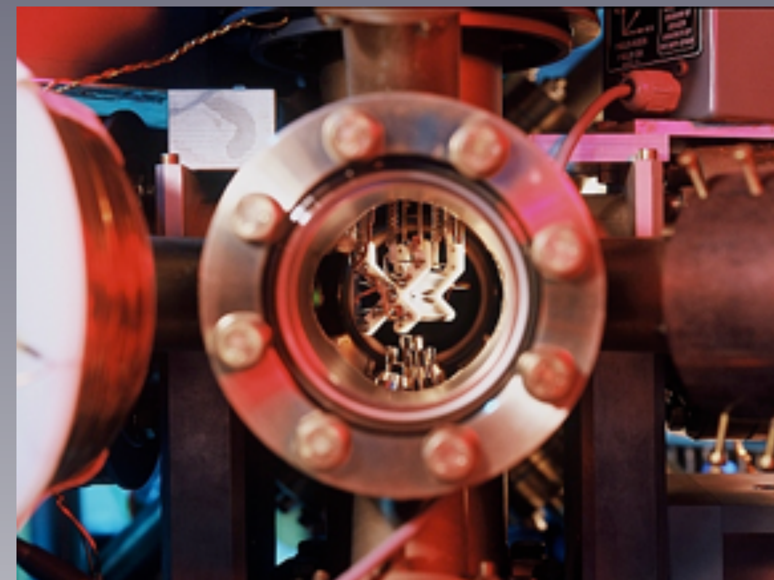
→ Quantum Information

can we make use of quantum mechanics to speed up information processing?

Realization

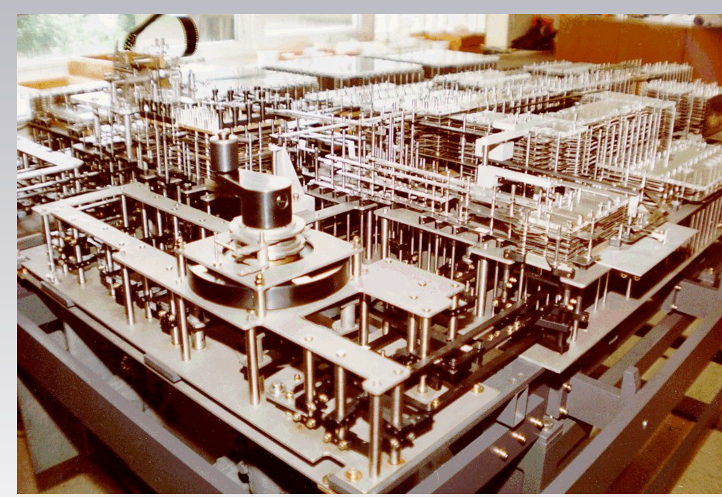


nuclear magnetic resonance
NMR



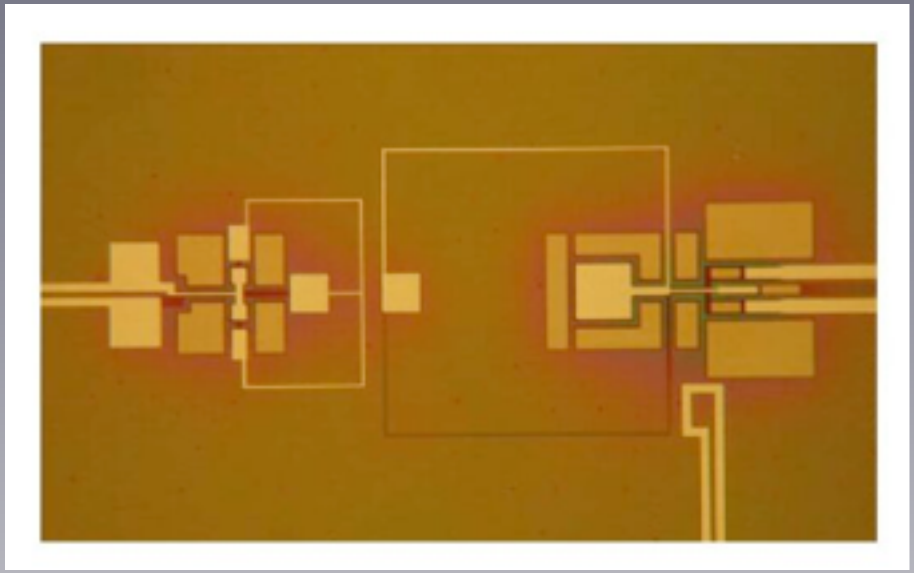
Ion Trap

Photons



Zuse Z1, 1936

Realization



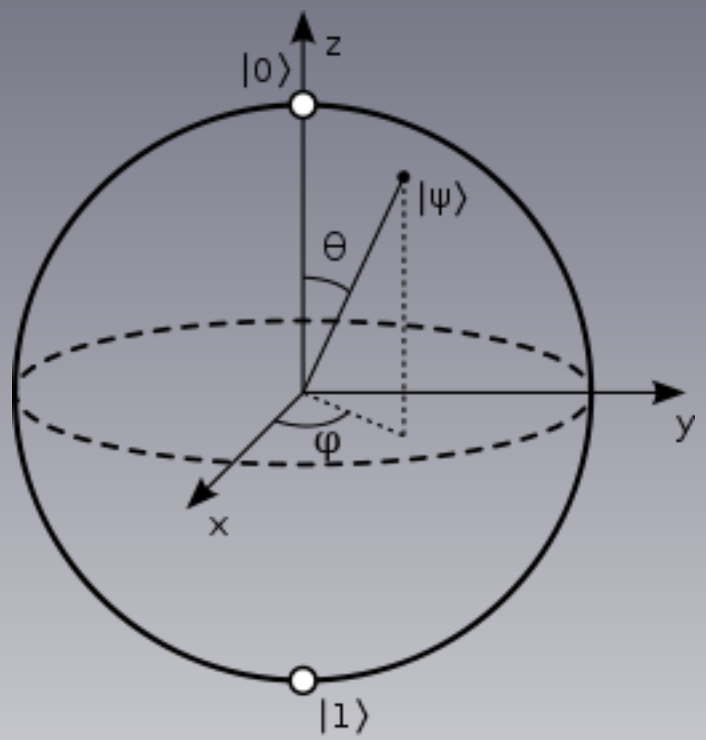
make use of nano-lithography
quantum chip

fundamental question
is there a fundamental limit for the size of a quantum system?

can we see quantum effects in a solid-state environment with billions of electrons/nuclei?

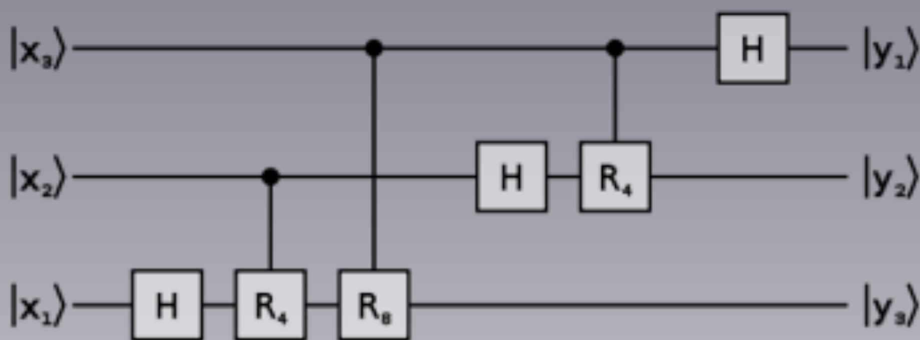
macroscopic quantum coherence

I Basic Concepts



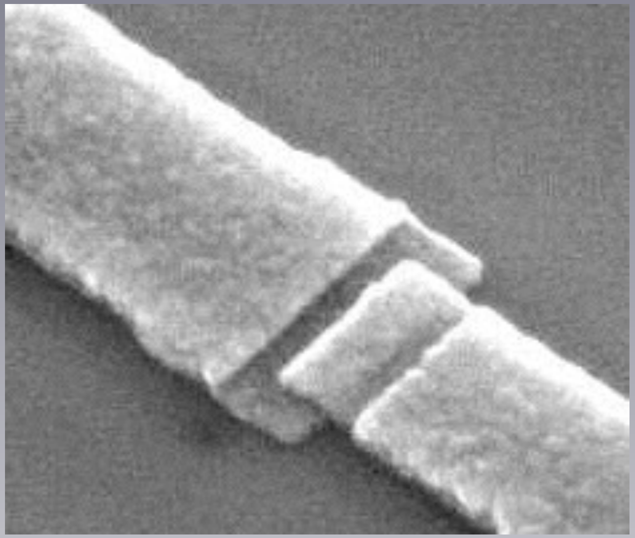
qubit/quantum bit
Bloch sphere
Rabi oscillation
open quantum systems
density matrix
decoherence/dephasing
Lindblad equation
Ramsey oscillation
echo techniques

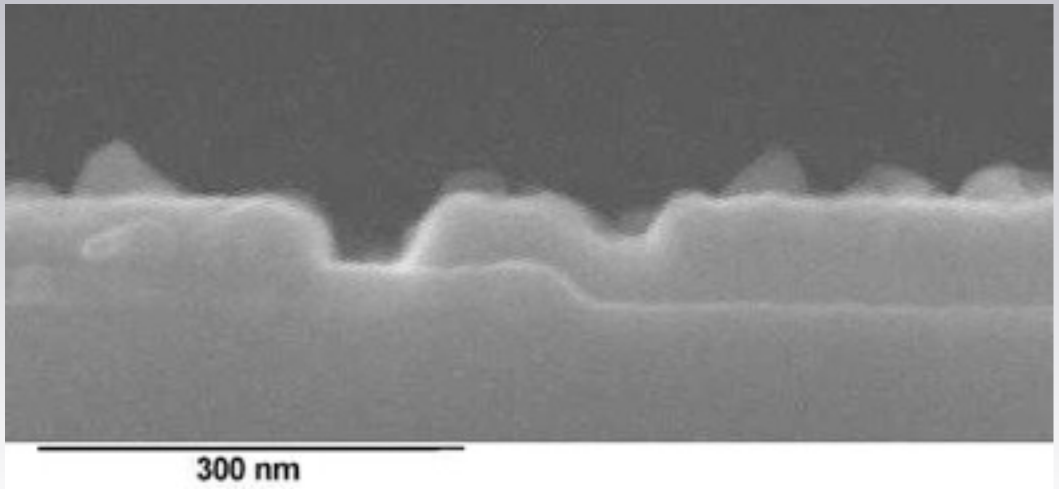
I Basic Concepts



multiple qubits
qubit coupling / qubit interaction
quantum gates
simple quantum algorithms
  Deutsch-Josza algorithm
  Grover search algorithm
state tomography
DiVincenzo criteria

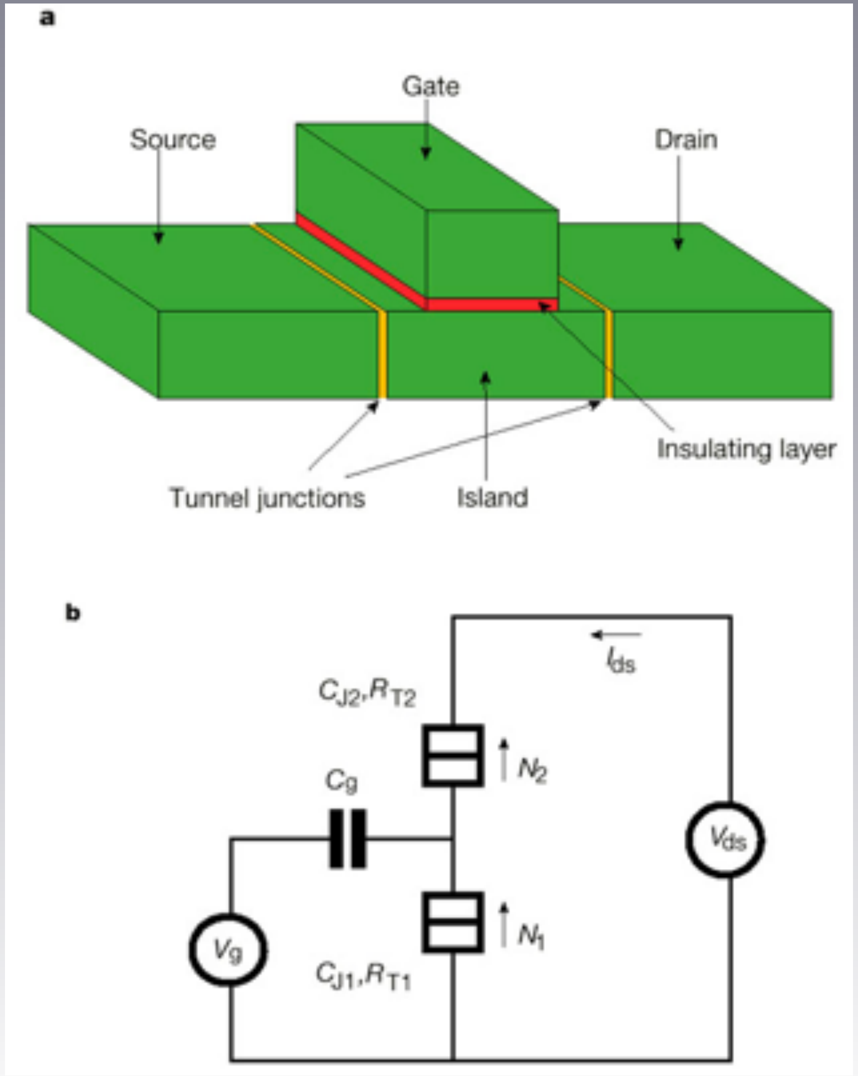
II Superconducting Electronics





Josephson junction
superconductors
tunnel junctions
Josephson equations
SQUID

II Superconducting Electronics



single electron transistor

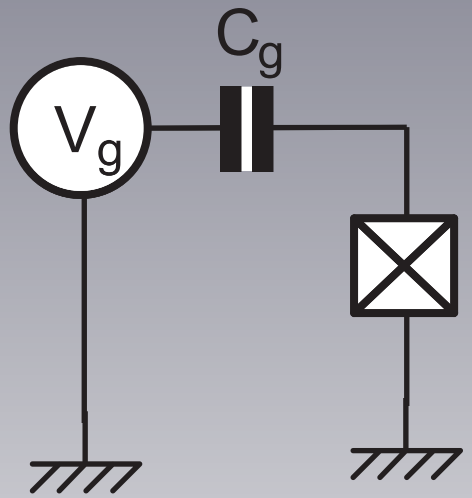
charging energy

Coulomb blockade

amplifying quantum signals

II Superconducting Electronics

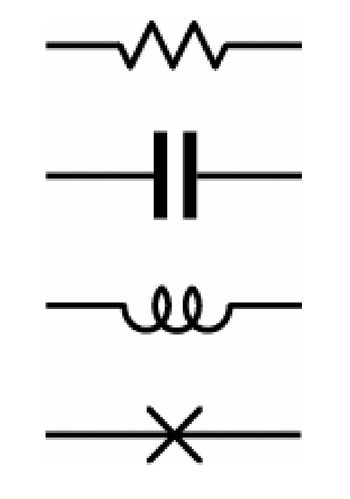
Quantum Circuits



charge and phase are conjugate variables

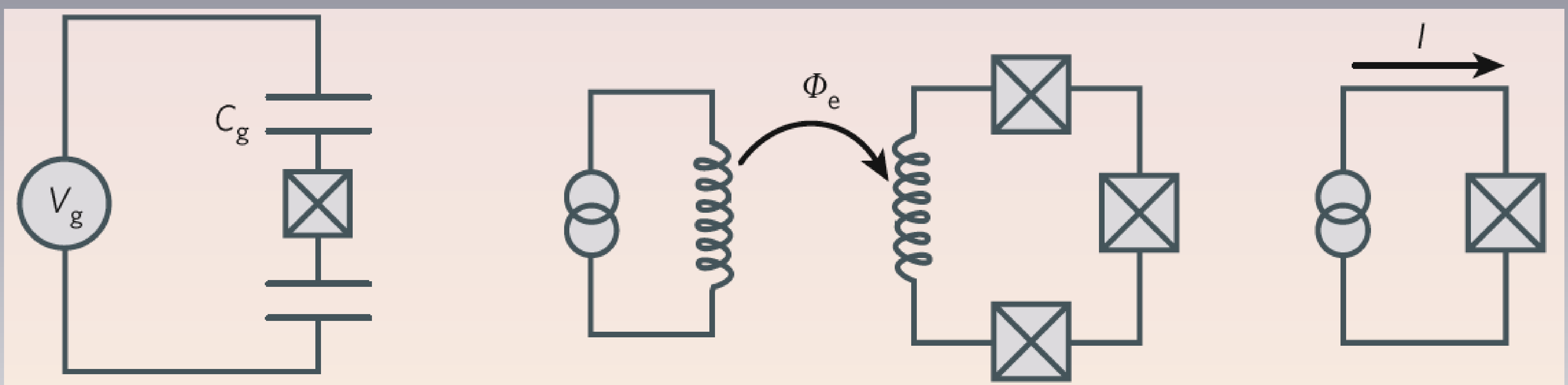
quantization of a circuit

Circuit Elements



II Superconducting Electronics

Superconducting Qubits



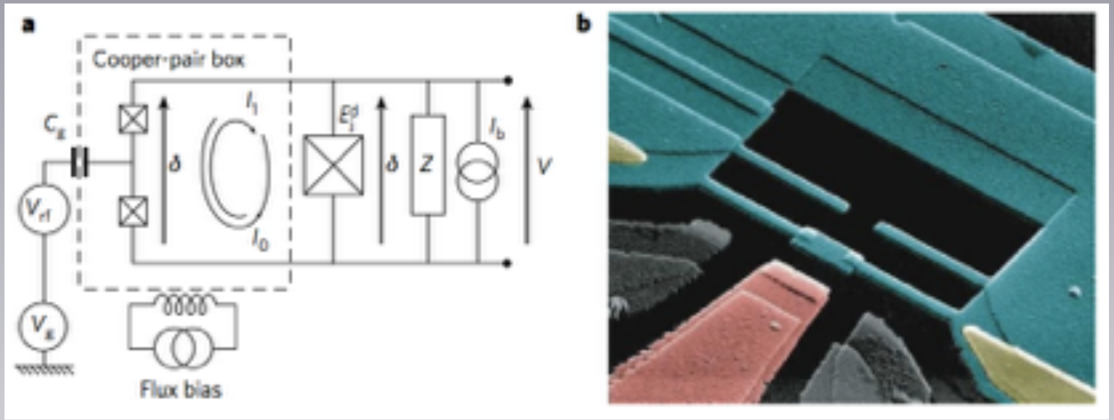
Charge Qubit

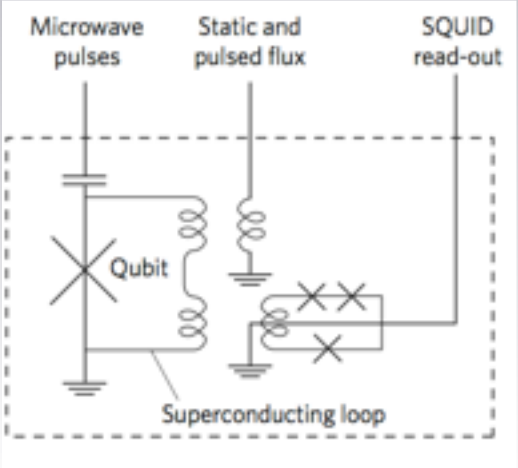
Flux Qubit

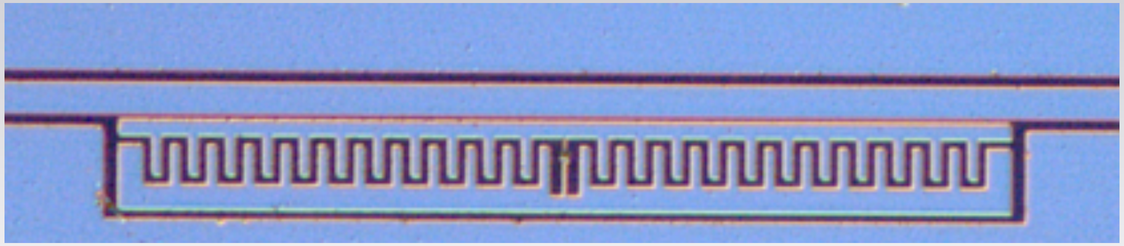
Phase Qubit

II Superconducting Electronics

Qubit Measurement
Qubit (avoiding) Decoherence



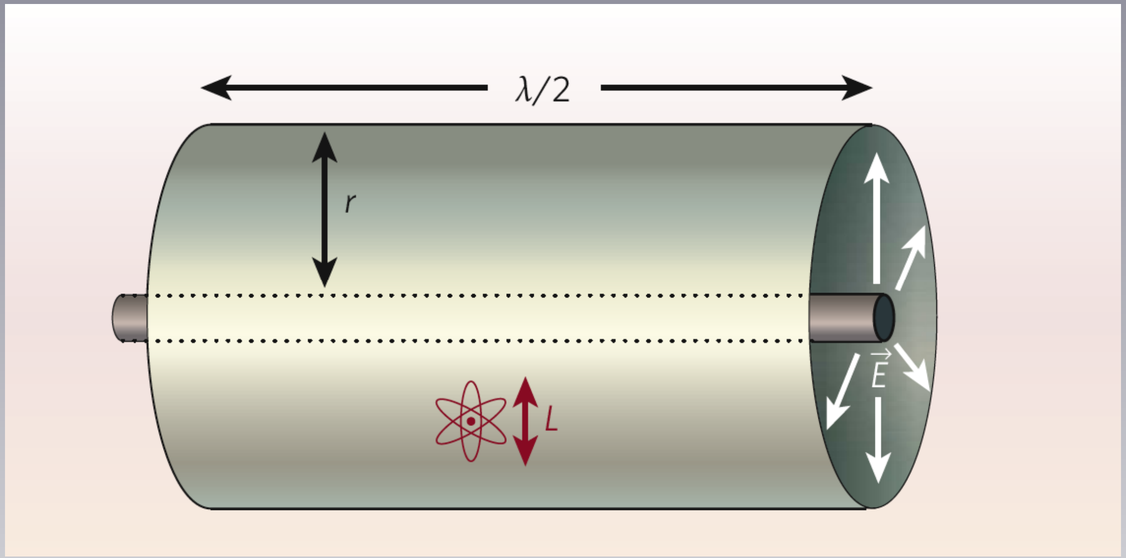


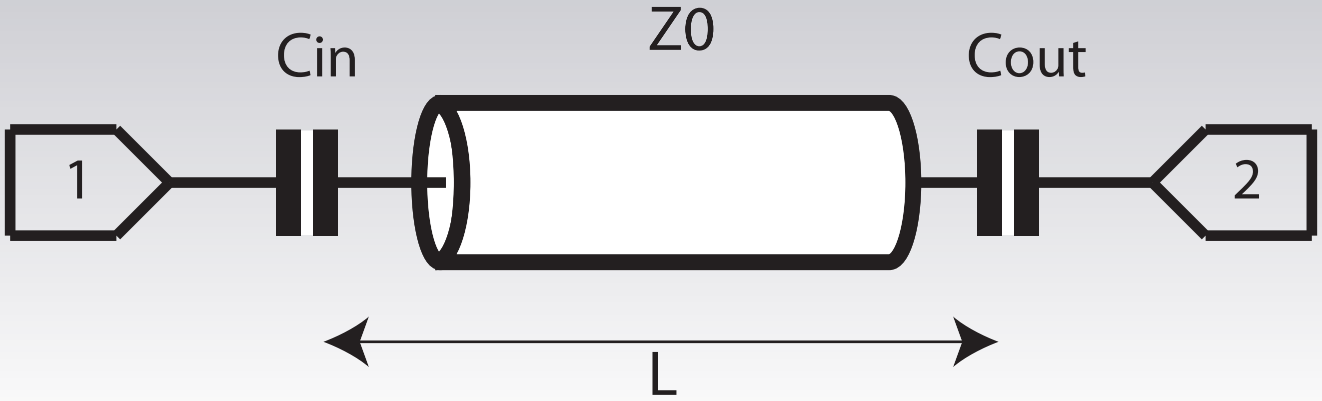


Transmon Qubit

II Superconducting Electronics

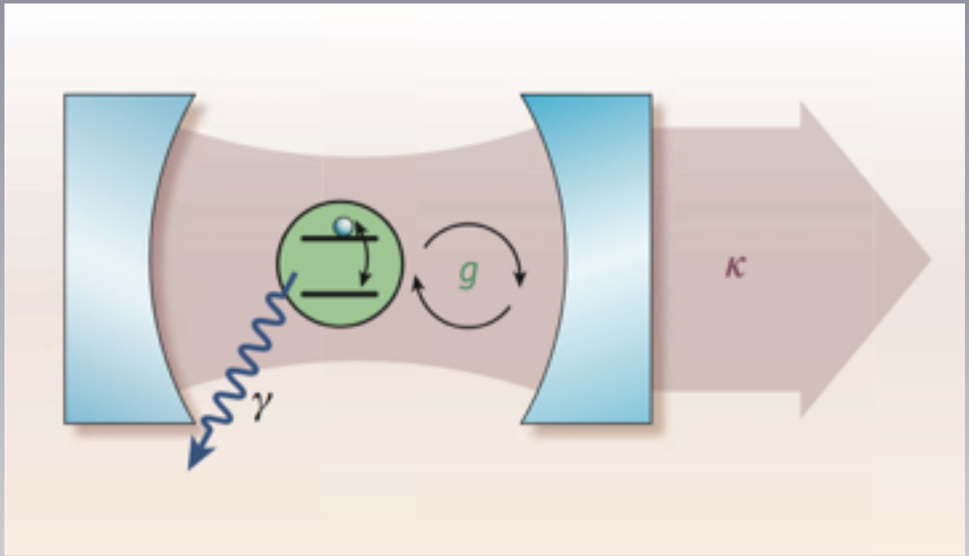
Transmission Line Resonators

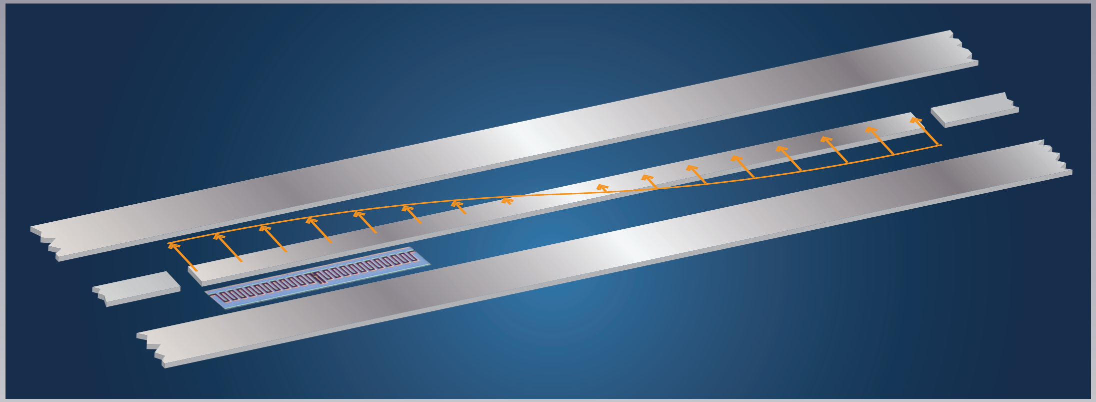




II Superconducting Electronics

circuit cavity QED

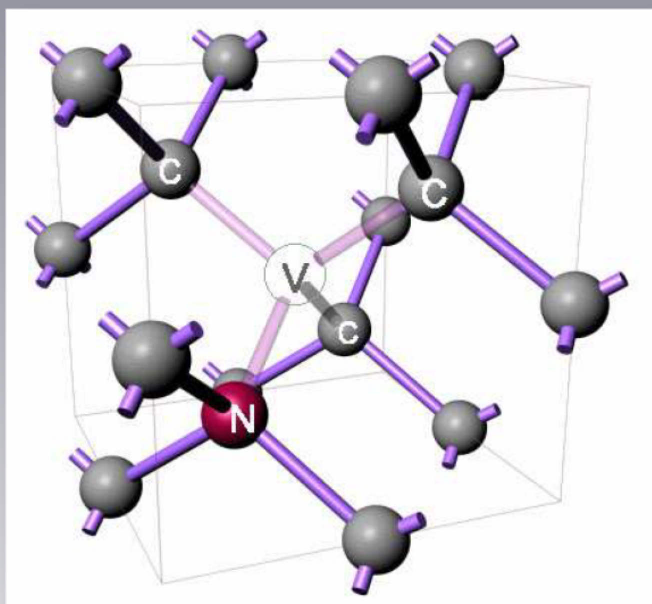


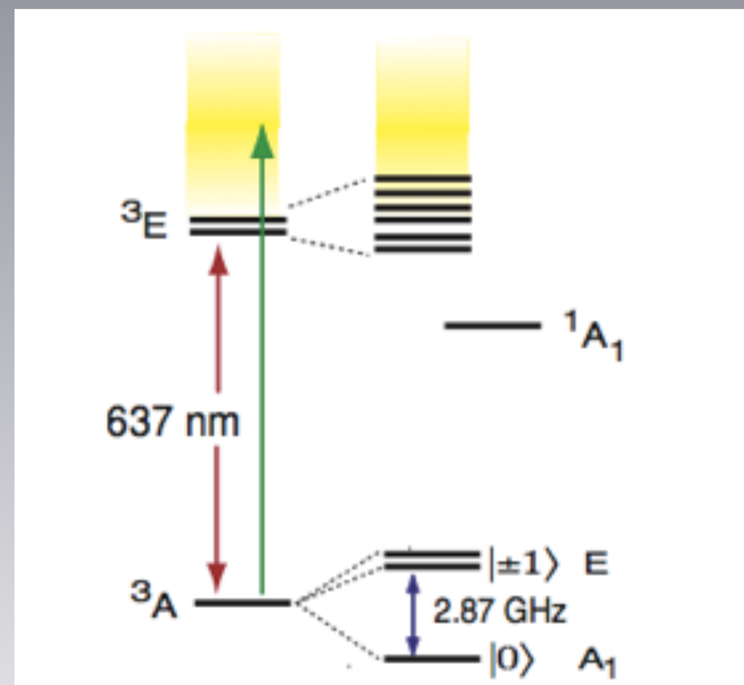


Jaynes-Cummings hamiltonian
vacuum Rabi oscillations
dispersive regime

III Other Solid-State Quantum Systems

Nitrogen Vacancy Color Center



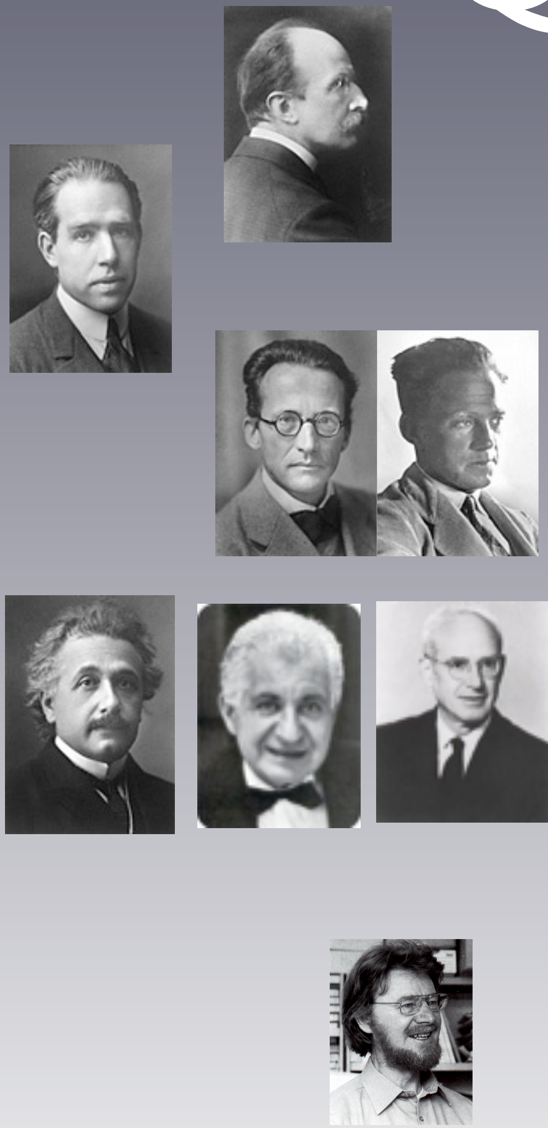


room temperature

optically detected magnetic resonance (ODMR)

coupling to N nucleus / ^{13}C nucleus

Quantum Physics



1900

- 1900 Planck: $\hbar$
- 1913 Bohr: model of the atom
- 1926 Schrödinger/Heisenberg
- 1935 Einstein/Podolski/Rosen
- 1963 Bell: inequalities

2000

Quantum Computing

1982 R. Feynman  Quantum Simulations

1985 D. Deutsch  Quantum Information Processing
Deutsch algorithm

1994 P. Shor  Prime factorization

1995 P. Shor Quantum Error Correction

1996 L. Grover  Search in unstructured database

Homework Problems

python™

SciPy

SciPy (pronounced "Sigh Pie") is a Python-based ecosystem of open-source software for mathematics, science, and engineering. In particular, these are some of the core packages:

NumPy
Base N-dimensional array package

SciPy library
Fundamental library for scientific computing

Matplotlib
Comprehensive 2D Plotting

IPython
Enhanced Interactive Console

Sympy
Symbolic mathematics

pandas
Data structures & analysis