Quantum Information with Solid-State Devices

VO 141.246

Dr. Johannes Majer

Lecture 1

ATOMINSTITUT

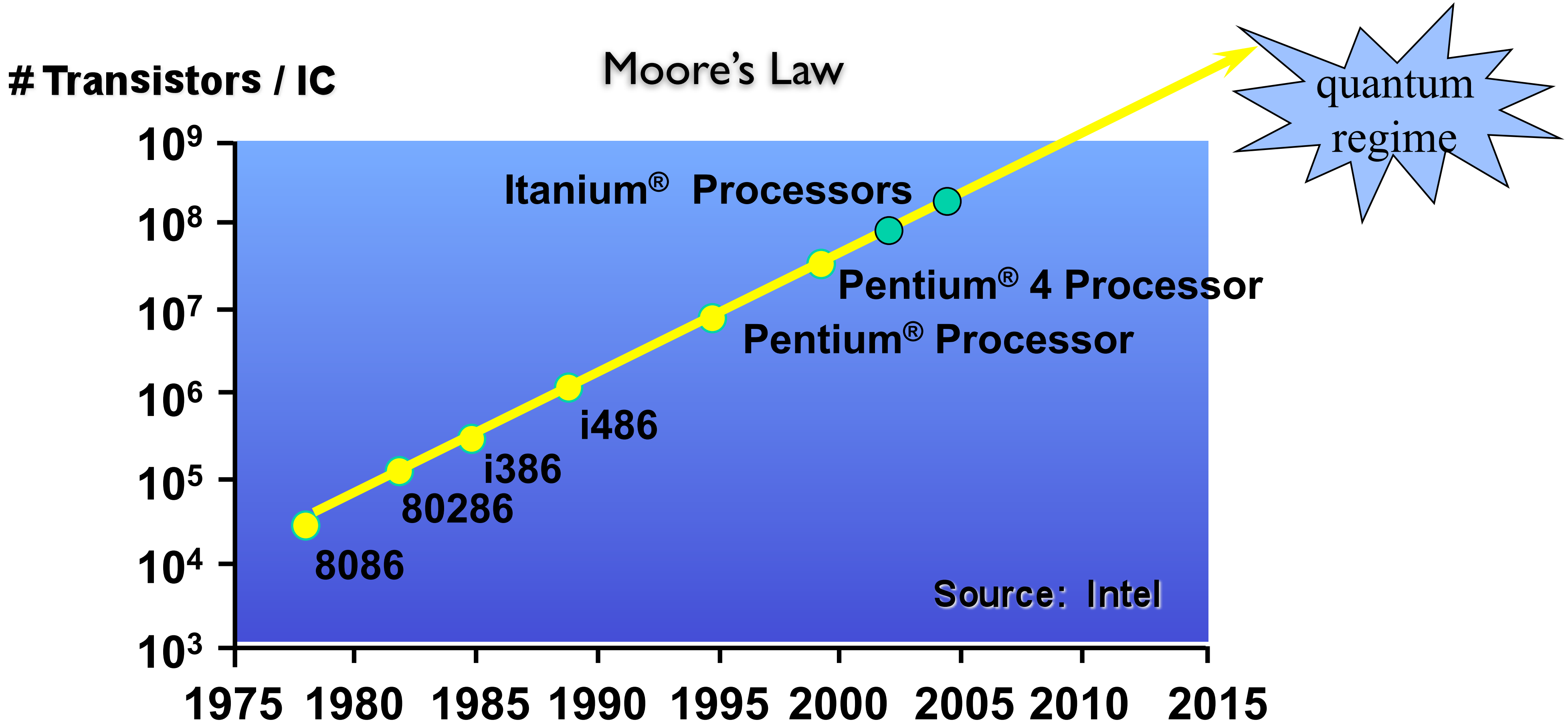
TU WIEN

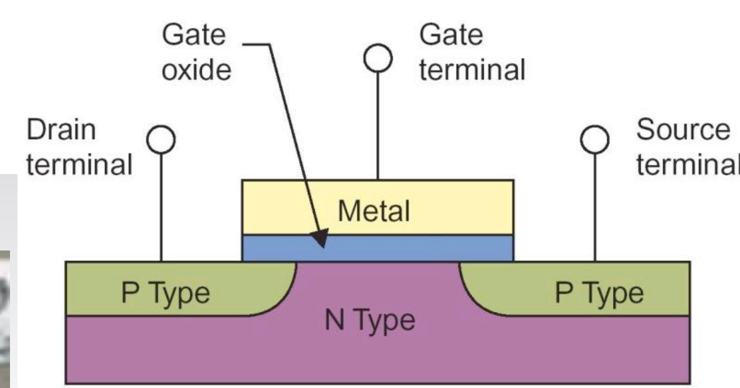
Overview

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

Administration

- Place & Time
- Website
- Exam

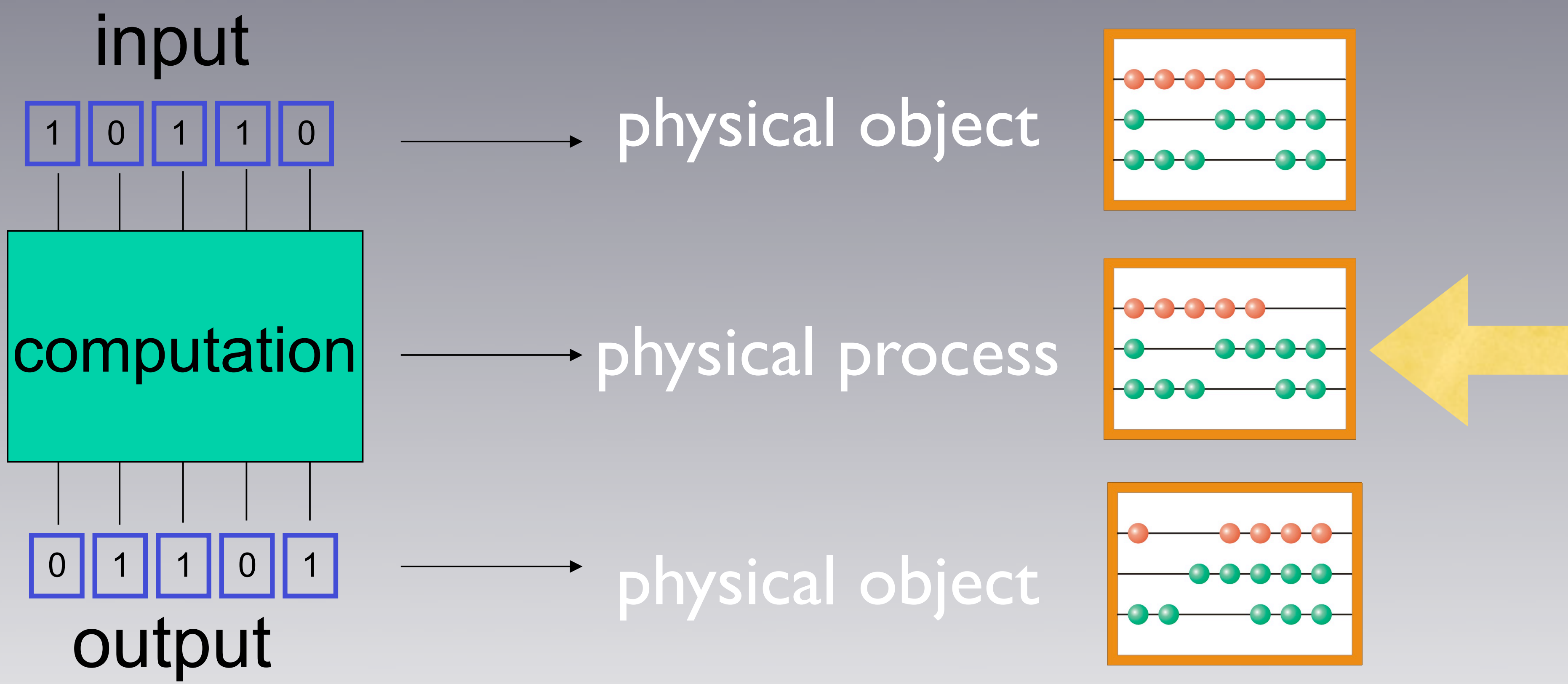




number of transistors doubles
every 2 years
Gorden Moore 1965

Information & Physics

information processing
is a physical process



information is physical
Rolf Landauer

Quantum Information

the fundamental laws of physics is quantum mechanics

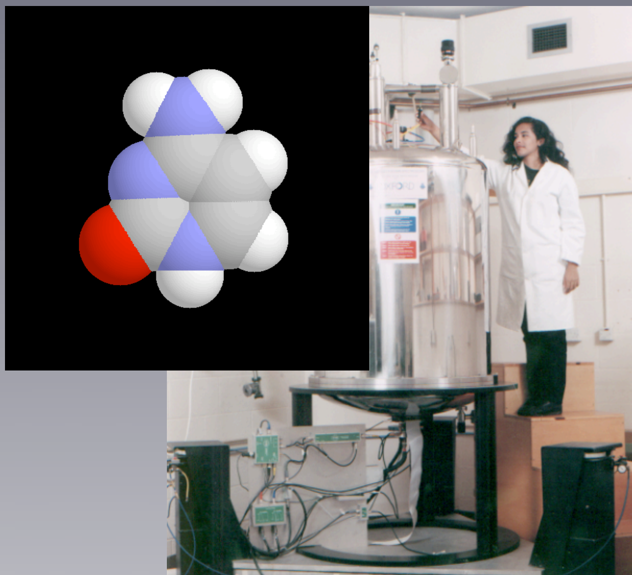
therefore the fundamental laws of information processing is quantum mechanics

David Deutsch

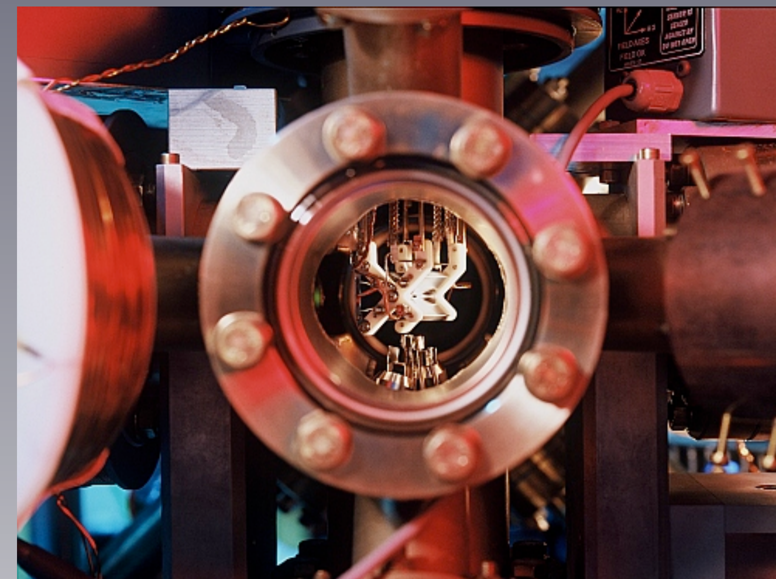
→ Quantum Information

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

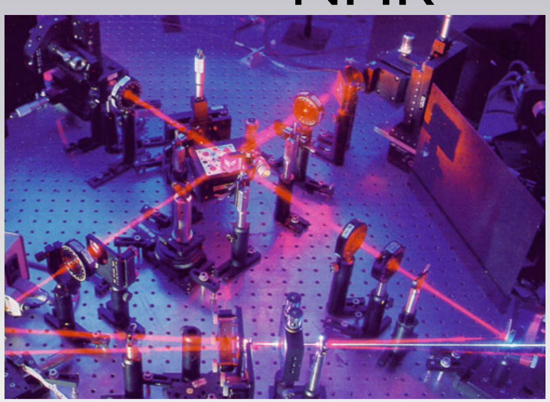
Realization



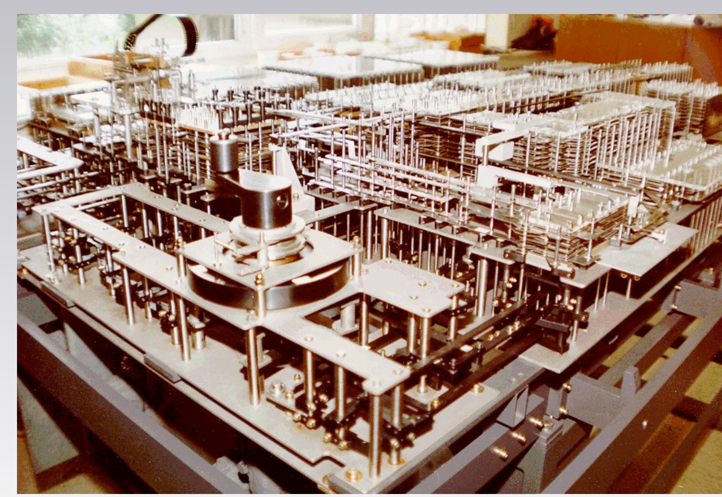
nuclear magnetic resonance
NMR



Ion Trap

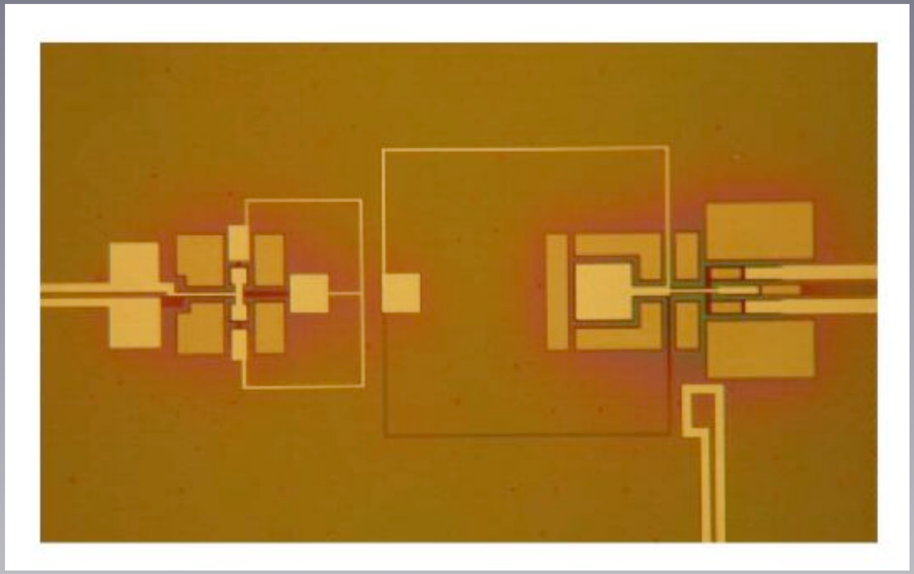


Photons



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?

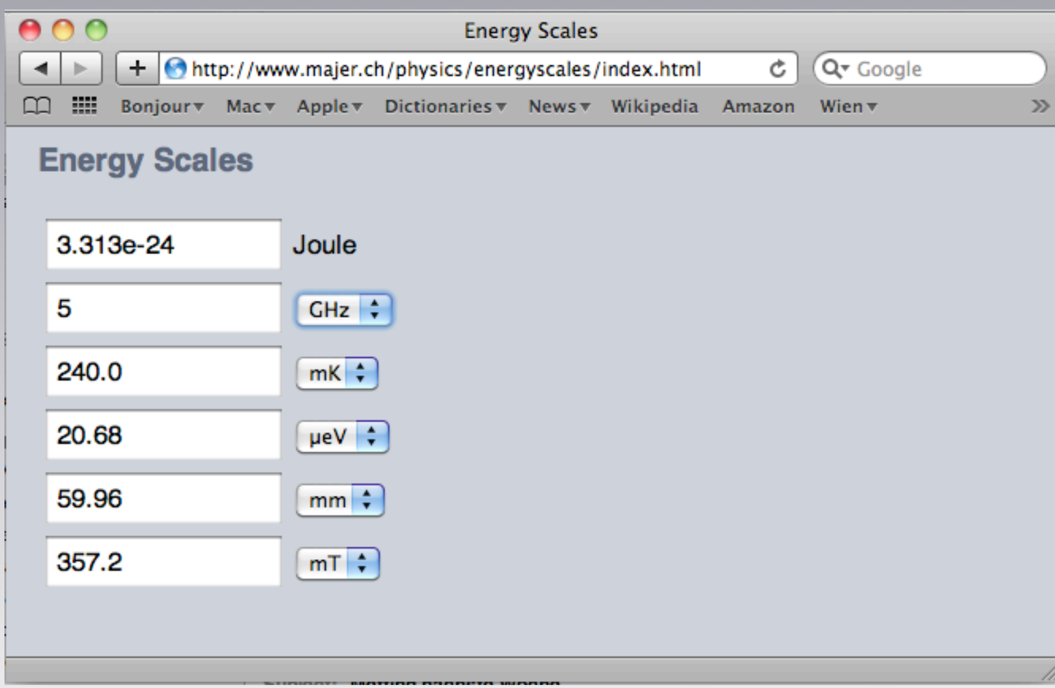
can we see quantum effects in a solid-state environment with billions of electrons/ nuclei?

macroscopic quantum coherence

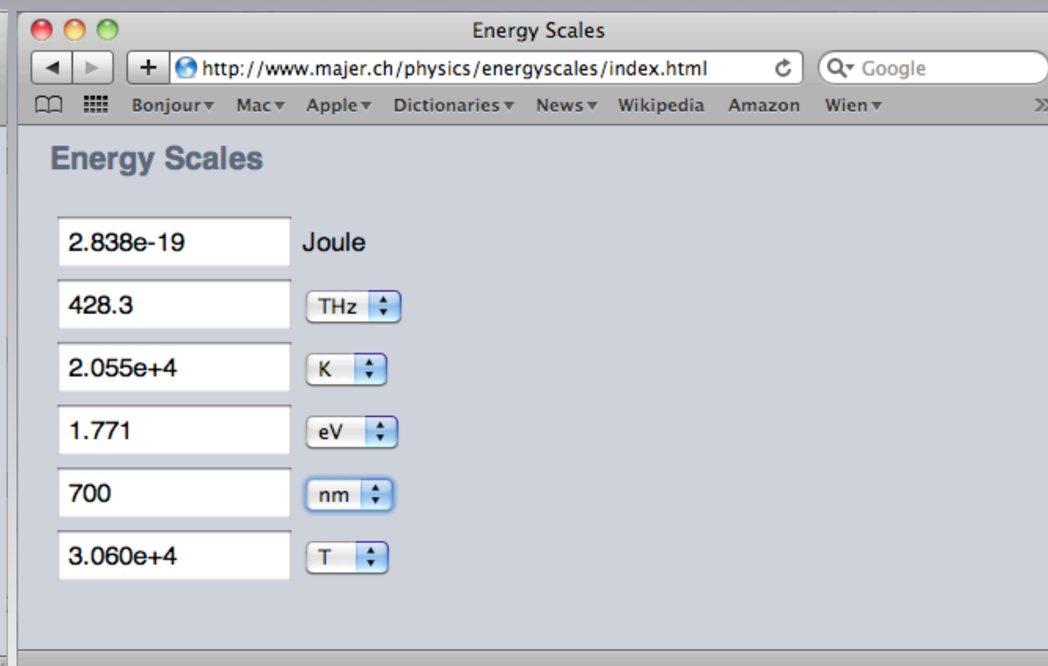
Energy Scales

$$E = h\nu$$

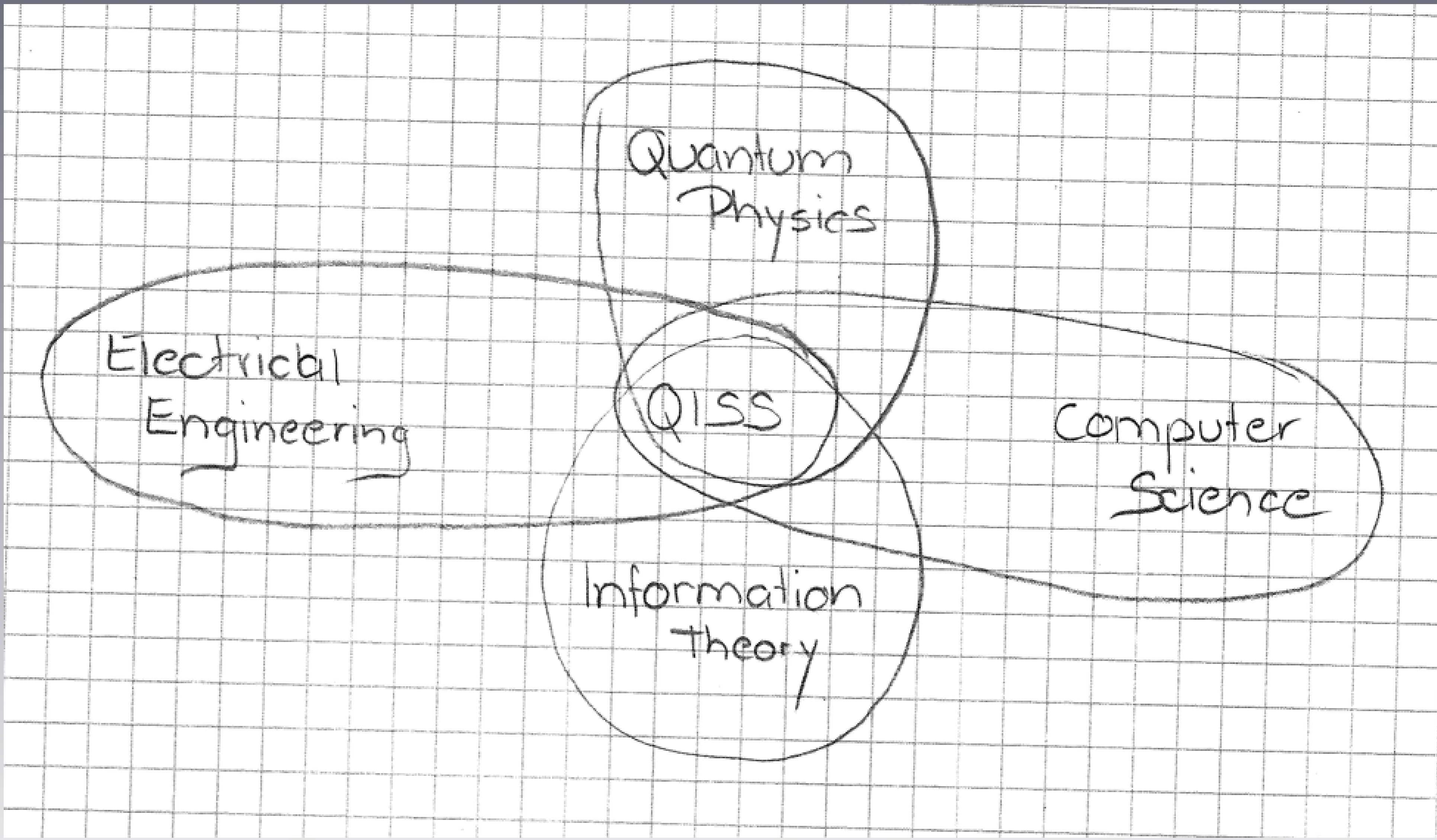
$$E = \frac{hc}{\lambda}$$



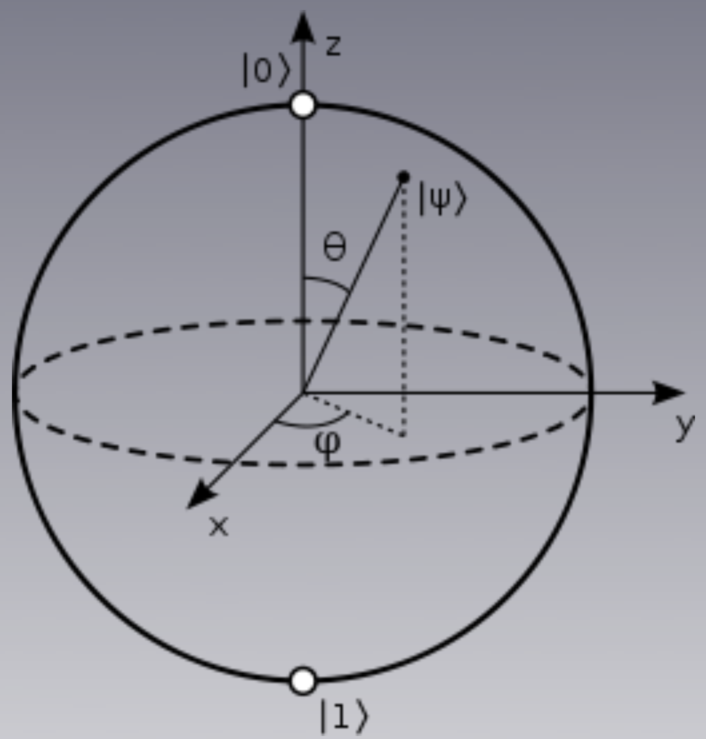
microwave photons



optical (red) photons

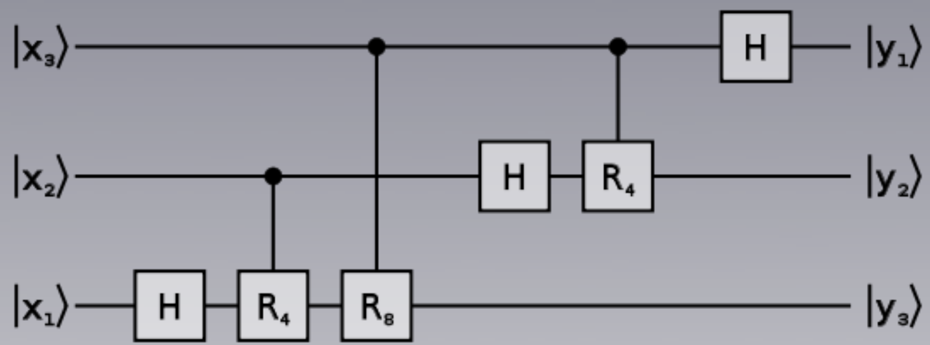

Quantum Physics
Electrical Engineering
QISS
Computer Science
Information Theory

I Basic Concepts



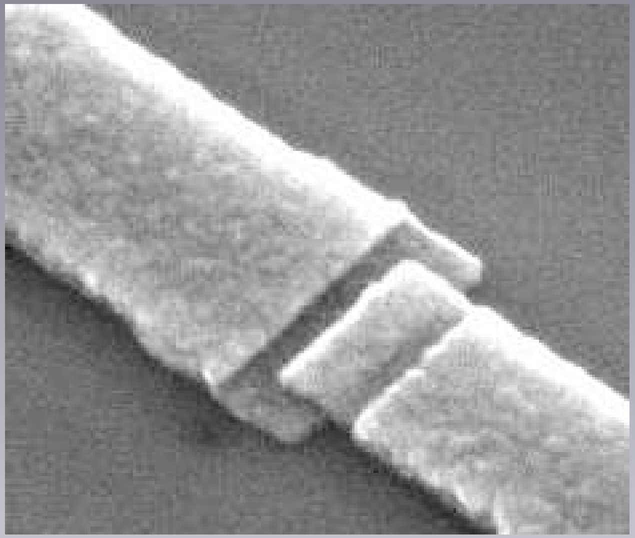
qubit/quantum bit
Bloch sphere
Rabi oscillation
open quantum systems
density matrix
decoherence/dephasing
Lindblad equation
Ramsey oscillation
echo techniques

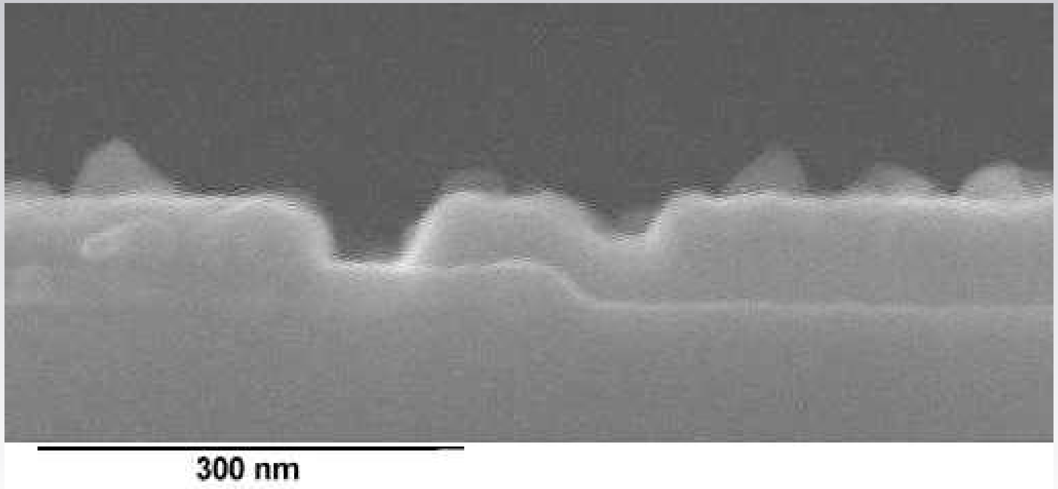
I Basic Concepts



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

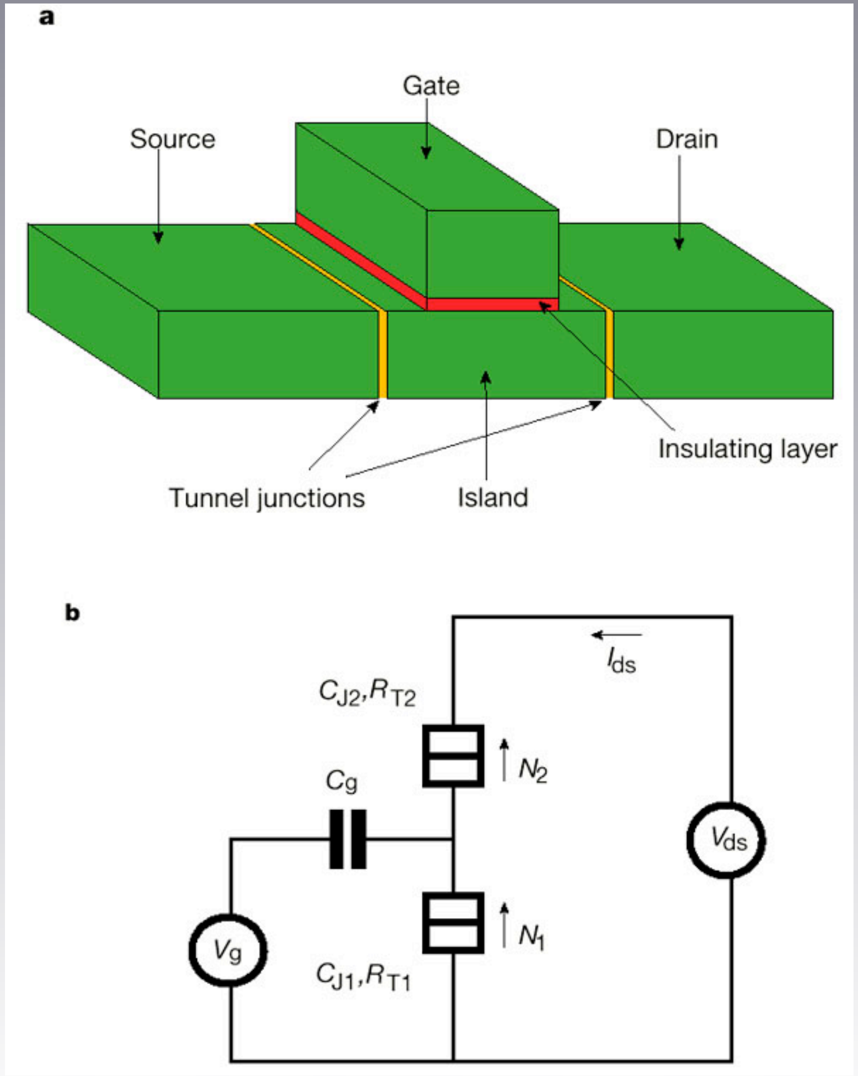
II Superconducting Electronics





Josephson junction
superconductors
tunnel junctions
Josephson equations
SQUID

II Superconducting Electronics



single electron transistor

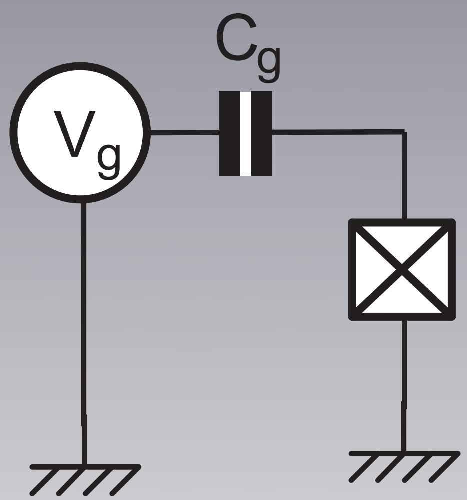
charging energy

Coulomb blockade

amplifying quantum signals

II Superconducting Electronics

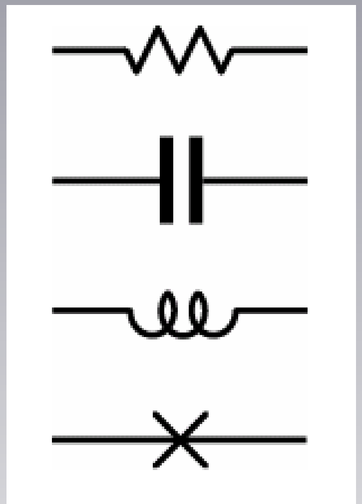
Quantum Circuits



charge and phase are conjugate variables

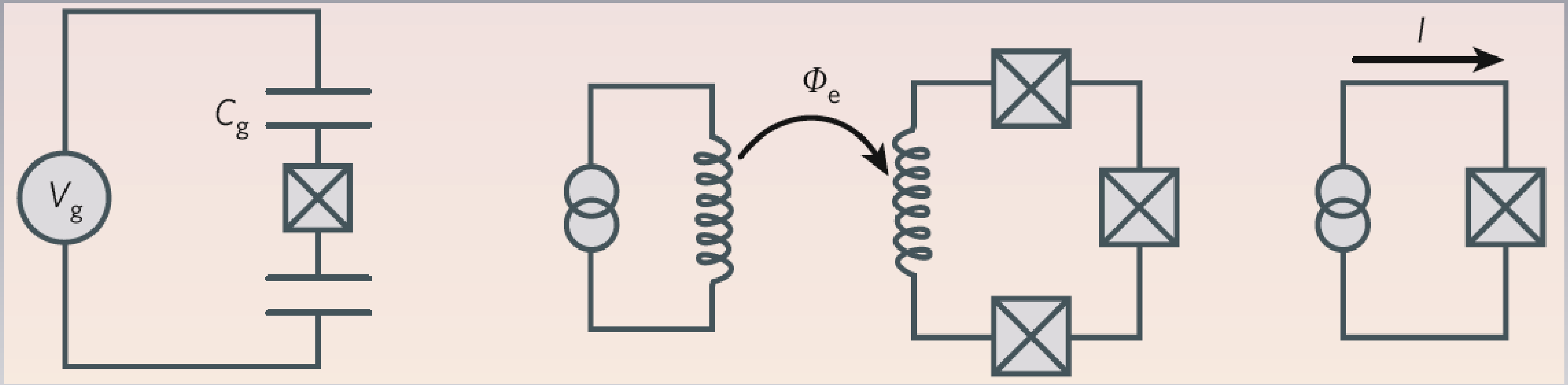
quantization of a circuit

Circuit Elements



II Superconducting Electronics

Superconducting Qubits



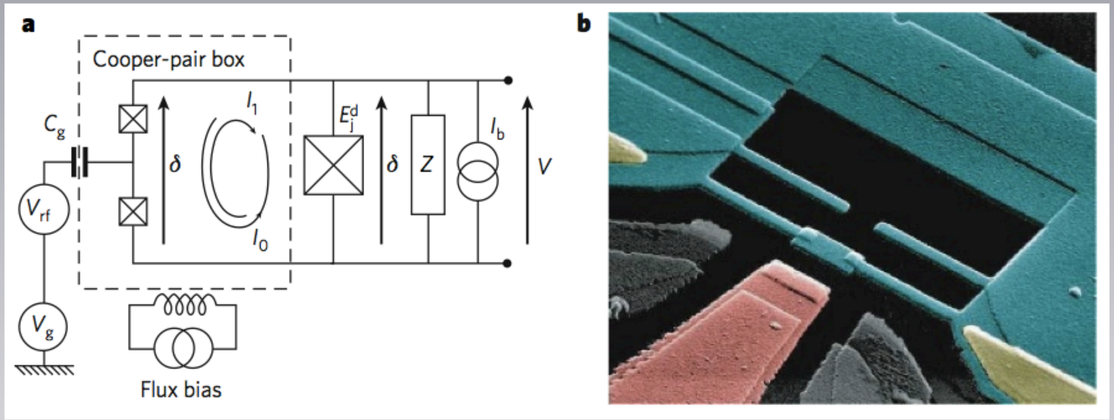
Charge Qubit

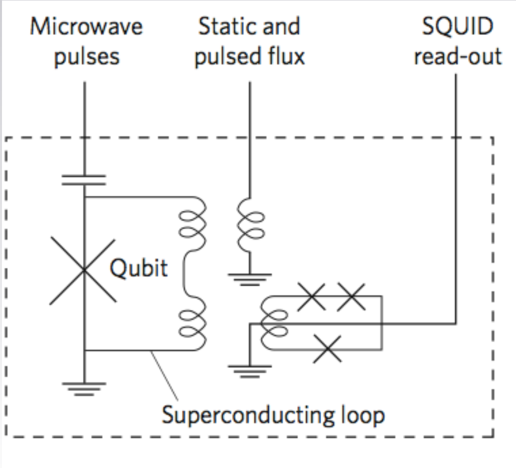
Flux Qubit

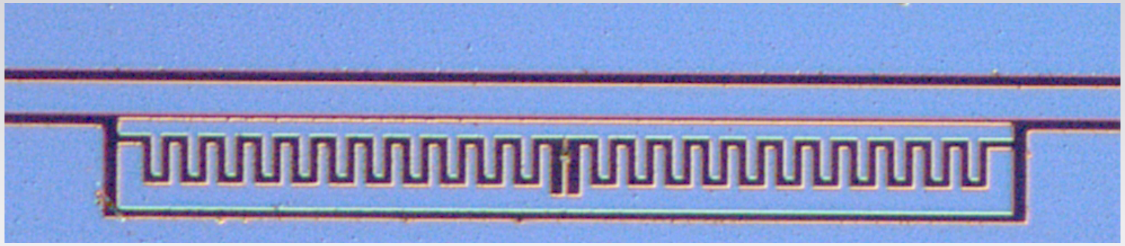
Phase Qubit

II Superconducting Electronics

Qubit Measurement
Qubit (avoiding) Decoherence



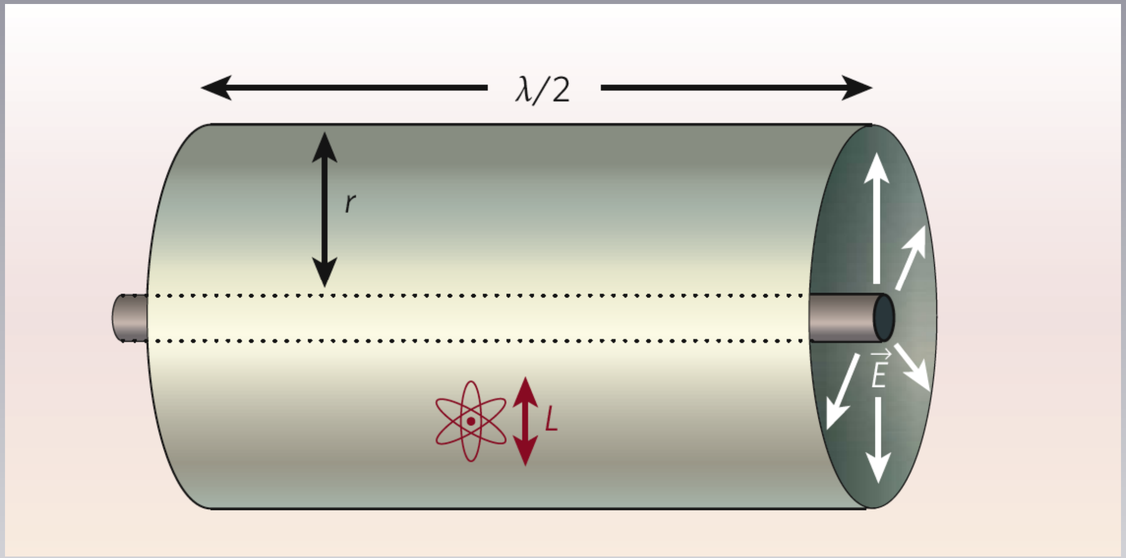


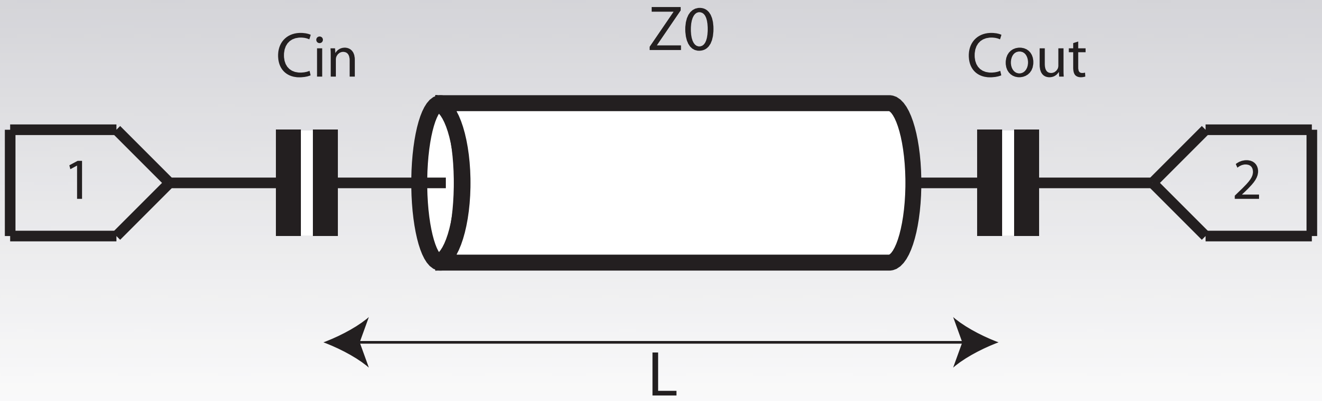


Transmon Qubit

II Superconducting Electronics

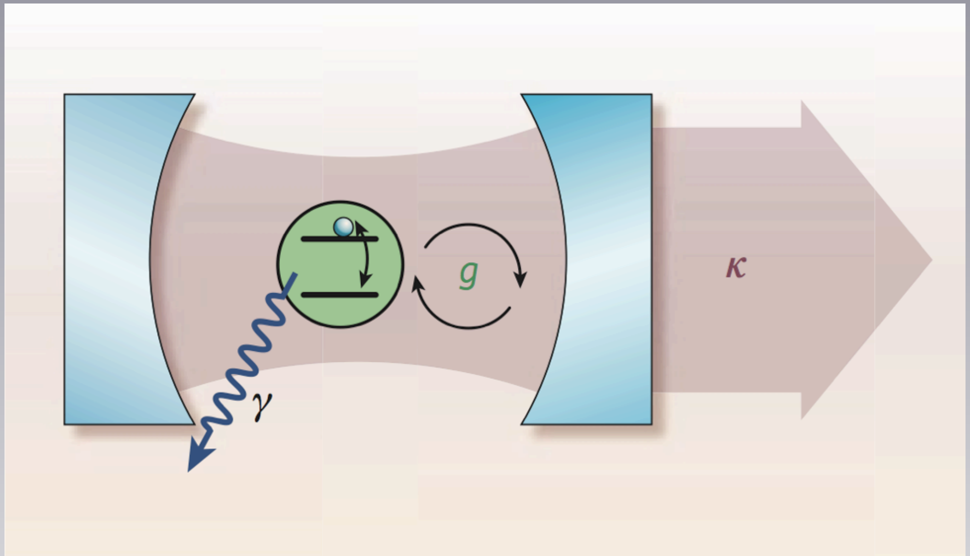
Transmission Line Resonators

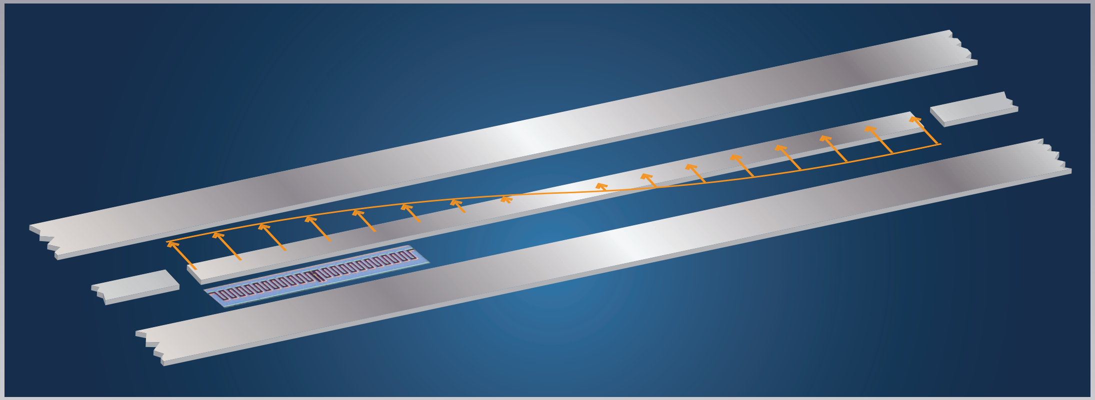




II Superconducting Electronics

circuit cavity QED

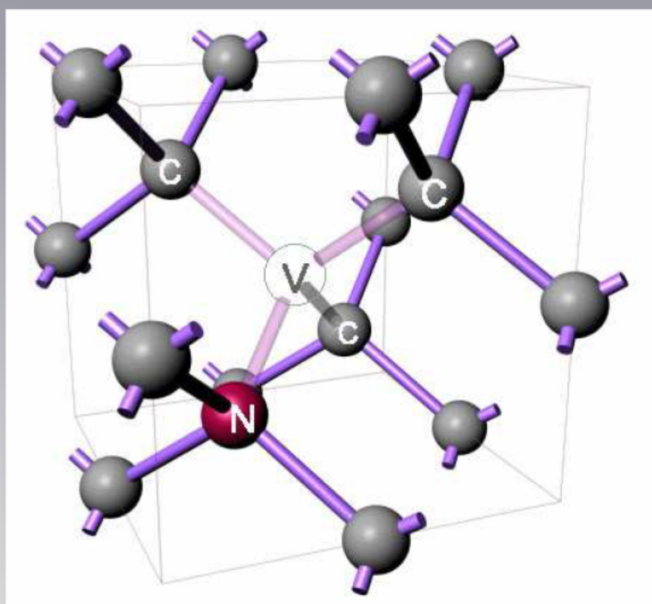


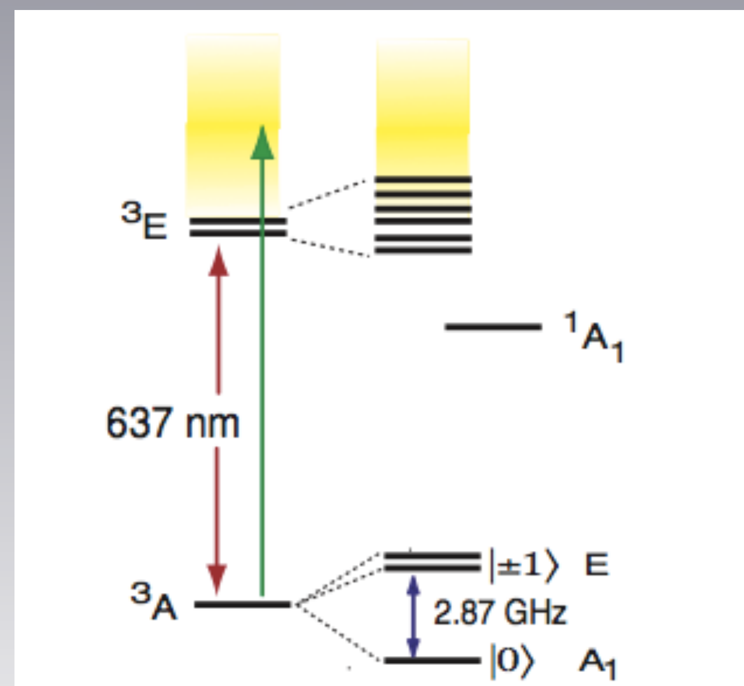


Jaynes-Cummings hamiltonian
vacuum Rabi oscillations
dispersive regime

III Other Solid-State Quantum Systems

Nitrogen Vacancy Color Center



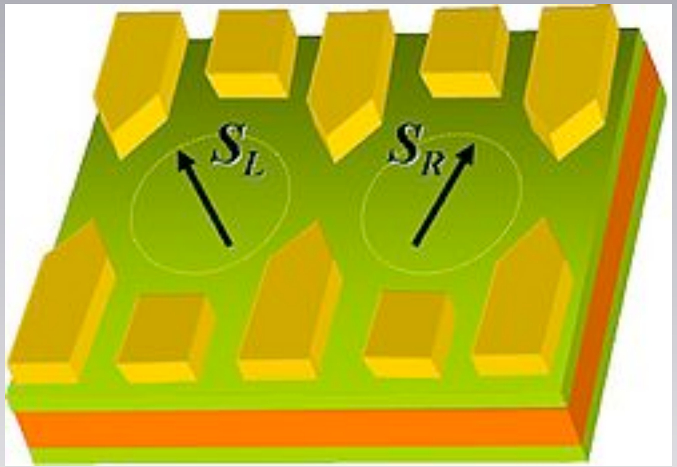


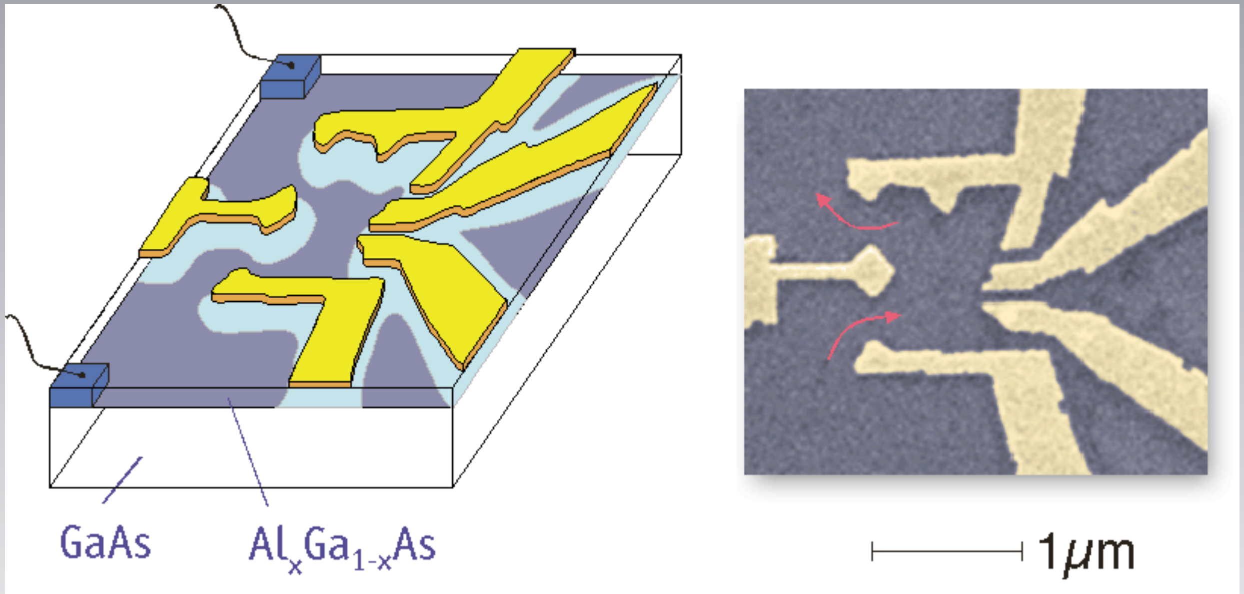
room temperature

optically detected magnetic resonance (ODMR)
coupling to N nucleus / ^{13}C nucleus

III Other Solid-State Quantum Systems

Semiconductor Quantum Dots



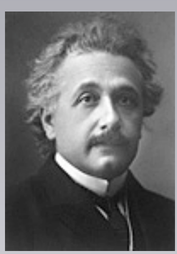
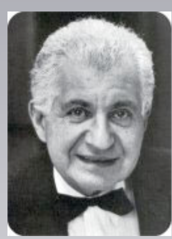
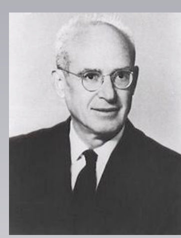
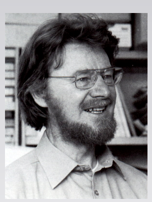


Loss-DiVincenzo proposal

Quantum Physics





1900 – 2000

1900 Planck: $\hbar$

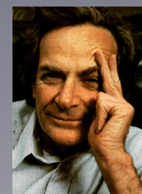
1913 Bohr: model of the atom

1926 Schrödinger/Heisenberg

1935 Einstein/Podolski/Rosen

1963 Bell: inequalities

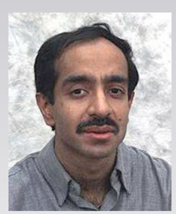
Quantum Computing

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