Quantum Information with Solid-State Devices

VO 141.246
SS2012
Dr. Johannes Majer

Lecture 1

ATOMINSTITUT

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 15:00-17:00
  no class next monday 19.3.2012
  next class 26.3.2012

- 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

Administration

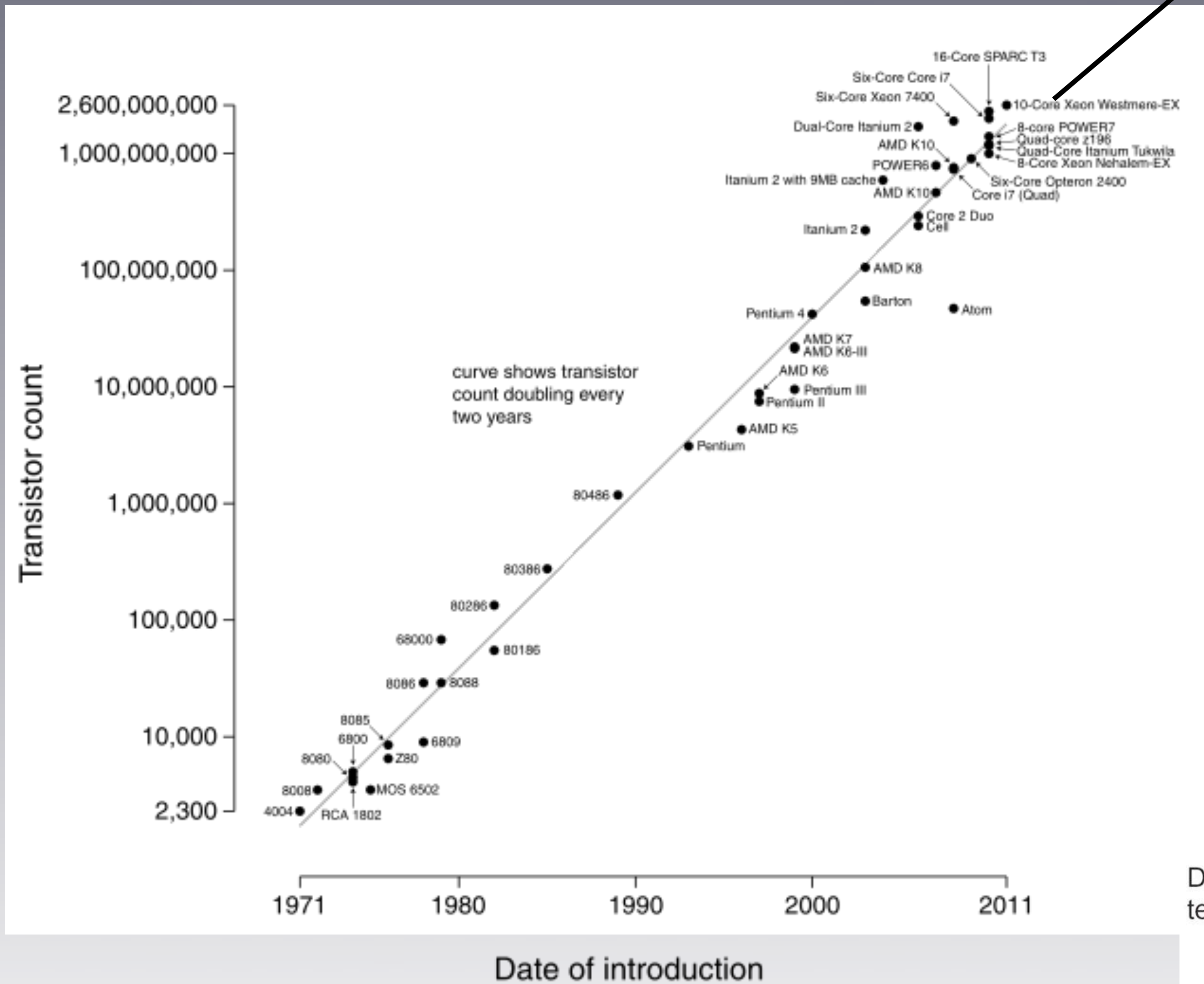
- Material

  Website:
  Slides & Handnotes
  Problem Sets & Solutions
  Extra material

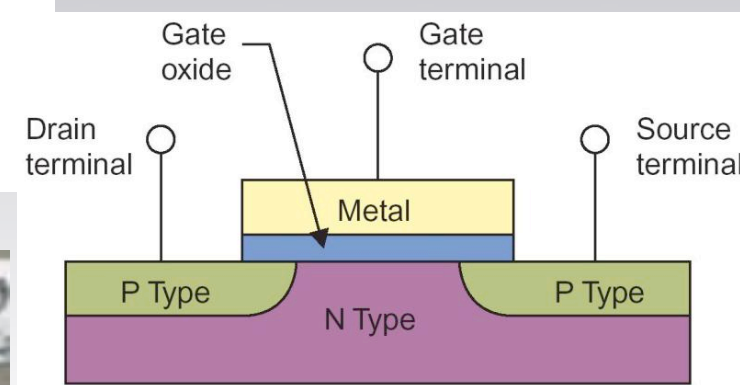
Moore’s Law

quantum regime

Microprocessor Transistor Counts 1971-2011 & Moore’s Law

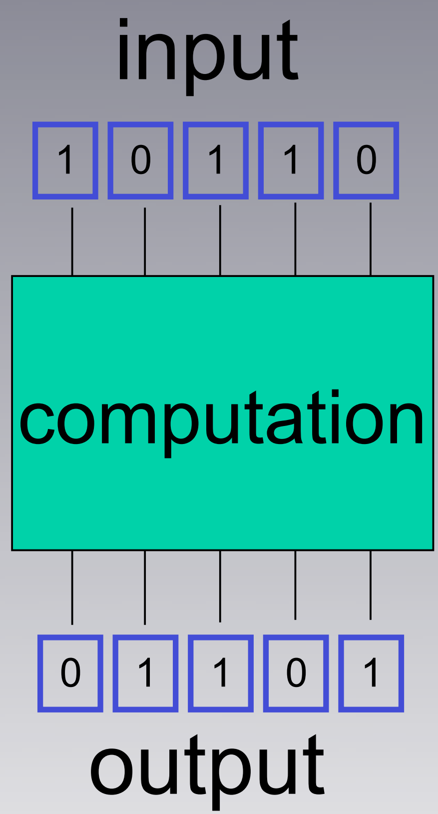


number of transistors doubles every 2 years
Gorden Moore 1965



Information & Physics

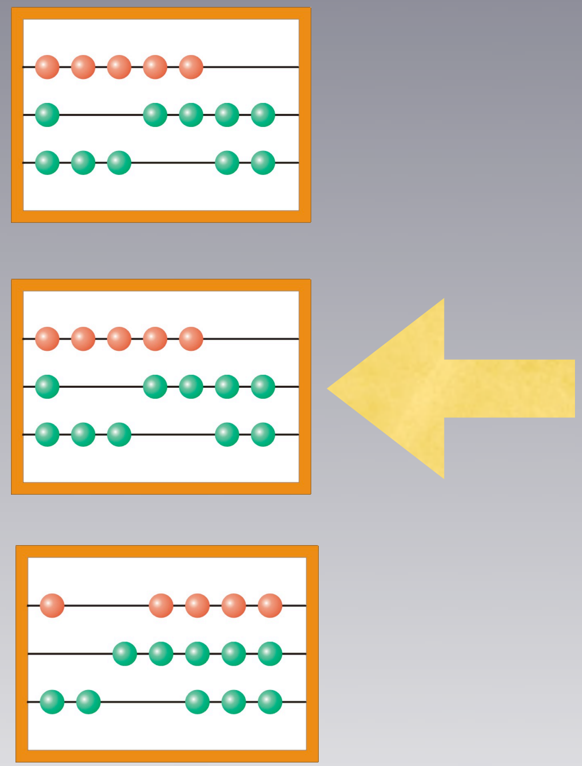
information processing
is a physical process



physical object

physical process

physical object



information is physical
Rolf Landauer

Quantum Information

the fundamental laws of physics
is quantum mechanics

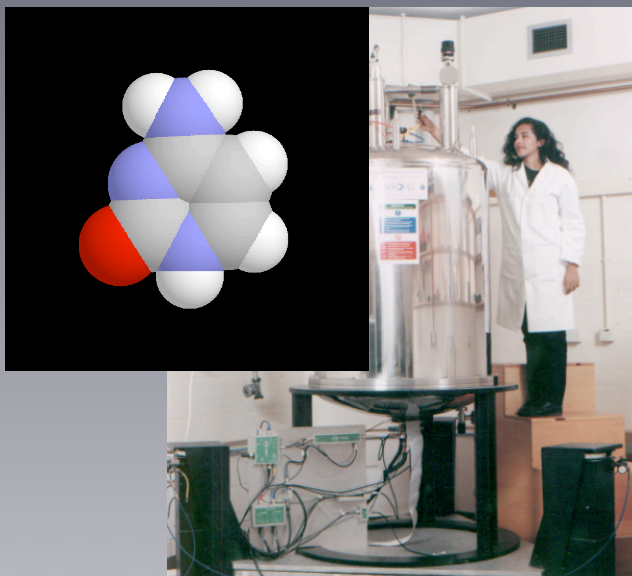
therefore the fundamental laws of
information processing is quantum
mechanics

David Deutsch

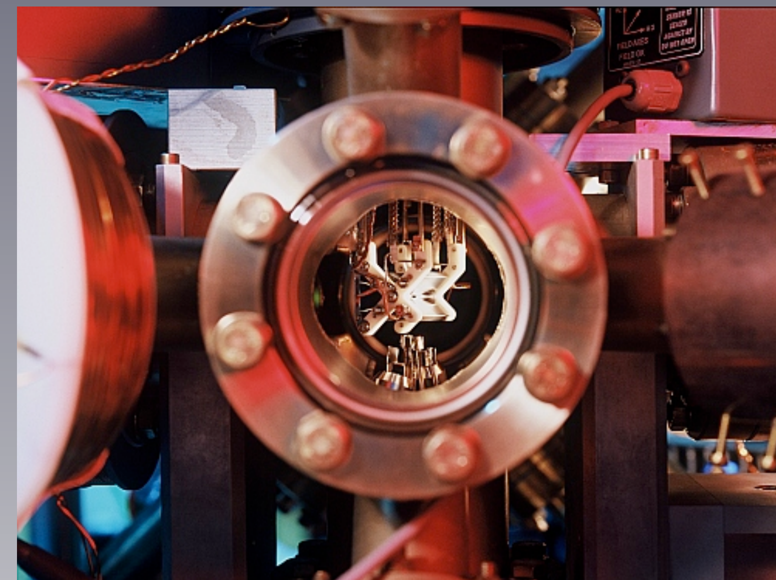
→ Quantum Information

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

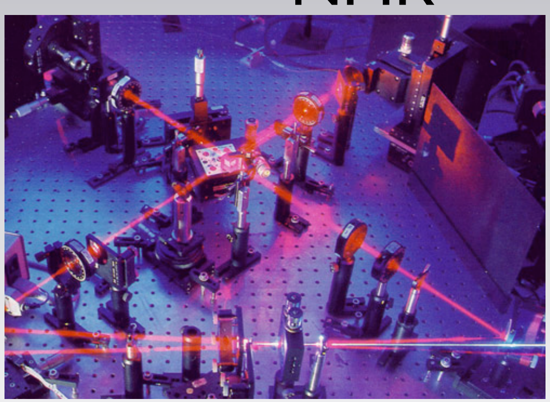
Realization



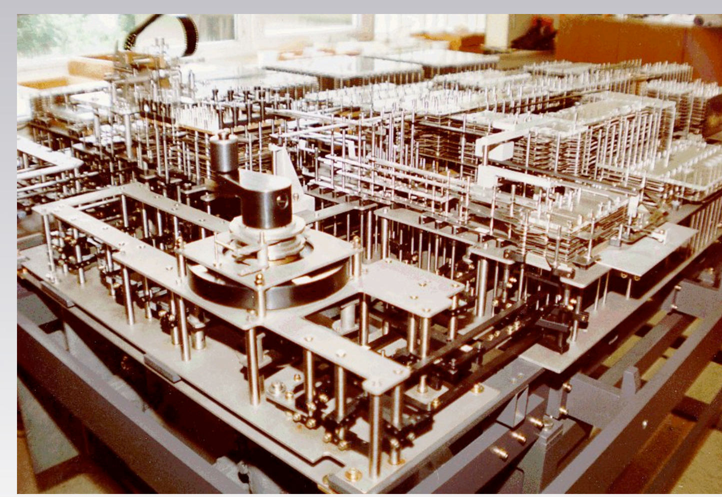
nuclear magnetic resonance
NMR



Ion Trap

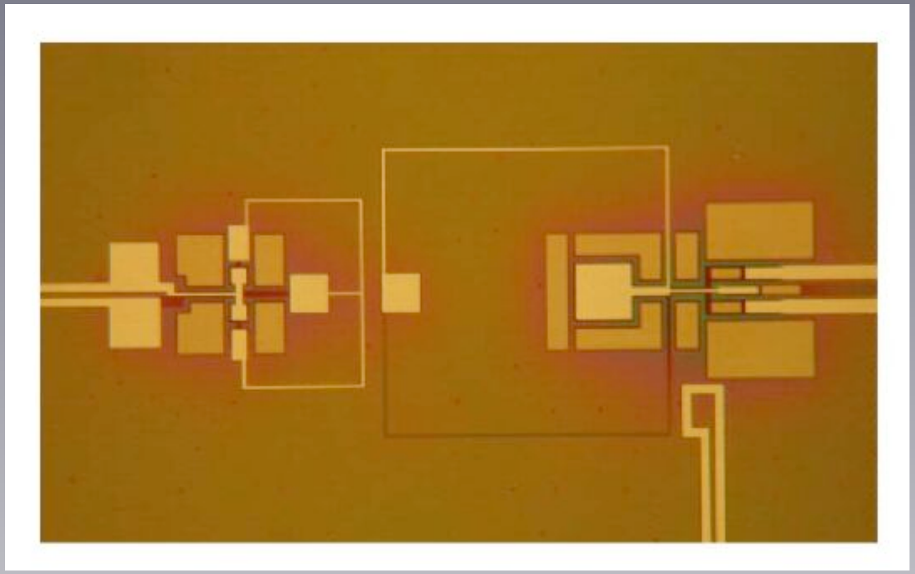


Photons



Zuse Z1, 1936

Realization



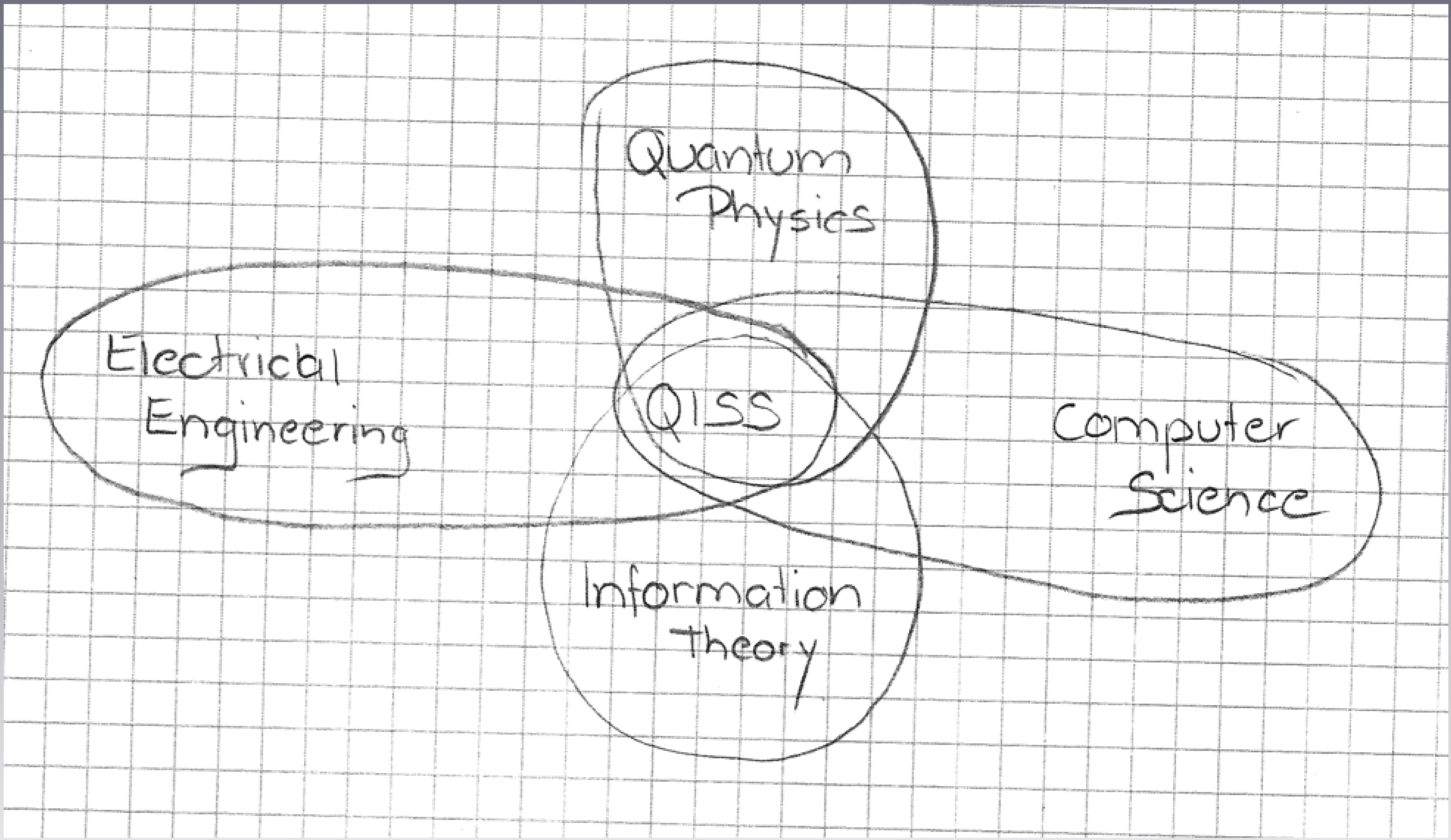
make use of nano-lithography
quantum chip

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?

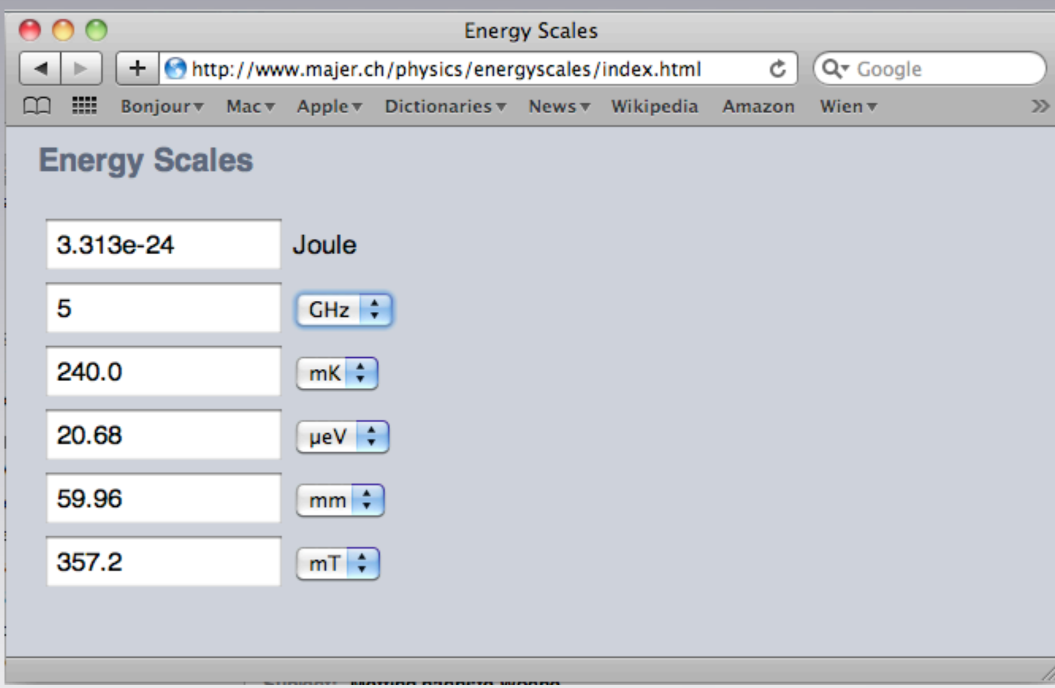
macroscopic quantum coherence

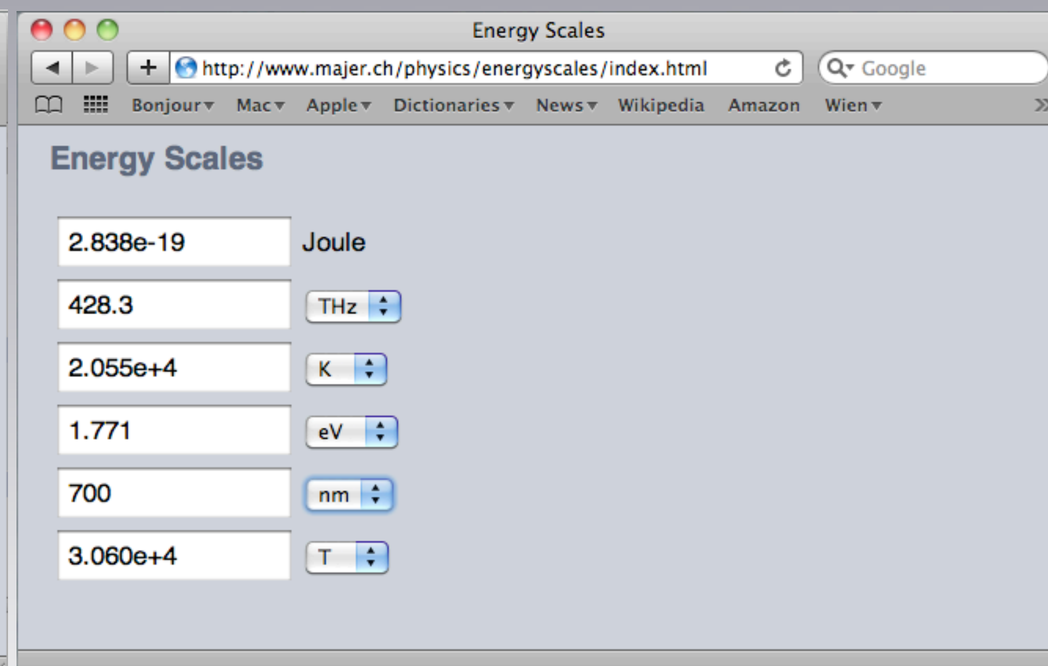

Quantum Physics
Electrical Engineering
QISS
Computer Science
Information Theory

Energy Scales

$$E = h\nu$$

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

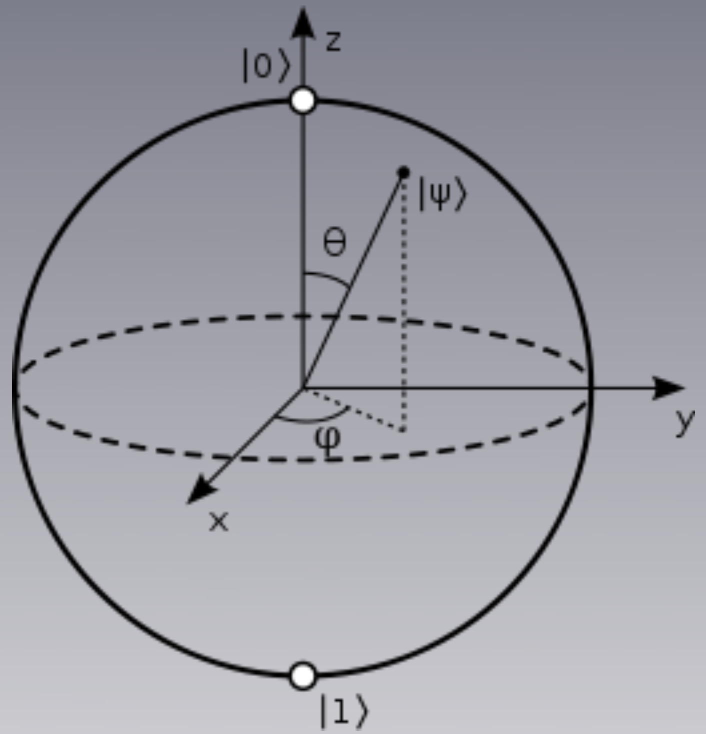




microwave photons

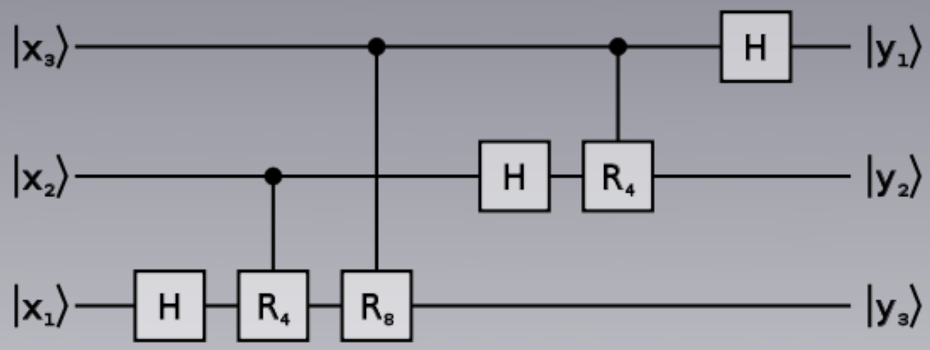
optical (red) photons

I Basic Concepts



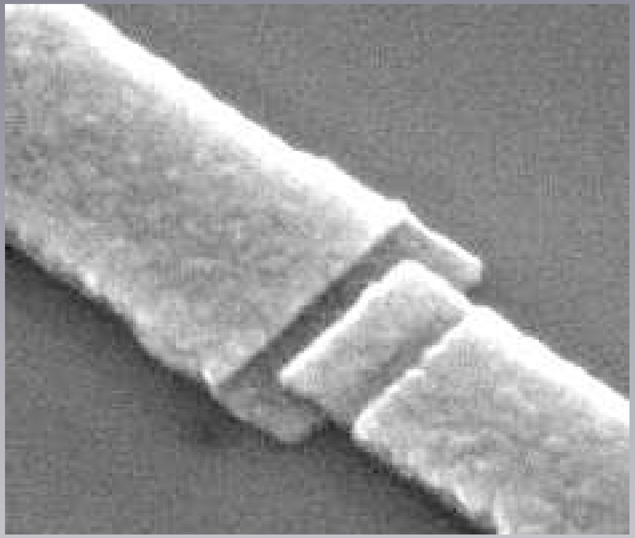
qubit/quantum bit
Bloch sphere
Rabi oscillation
open quantum systems
density matrix
decoherence/dephasing
Lindblad equation
Ramsey oscillation
echo techniques

I Basic Concepts

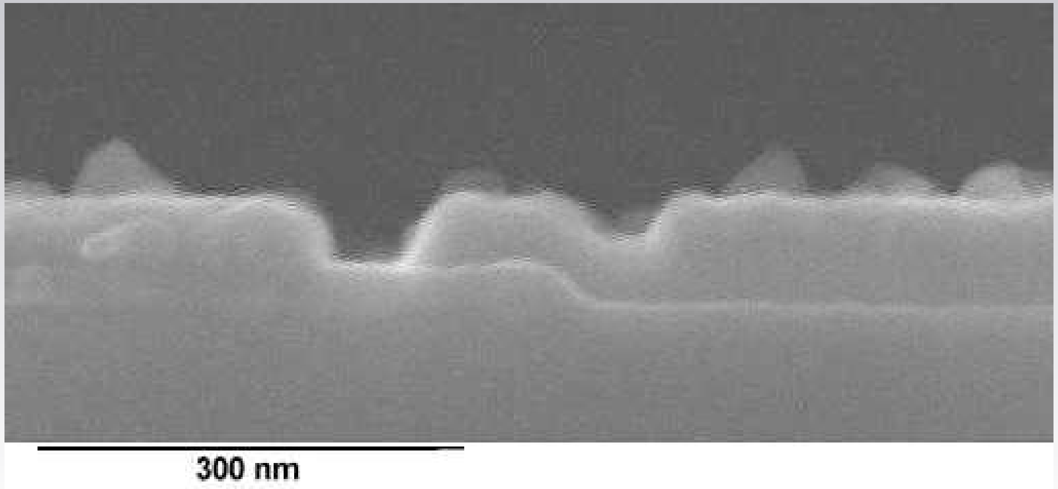


multiple qubits
qubit coupling / qubit interaction
quantum gates
simple quantum algorithms
  Deutsch-Josza algorithm
  Grover search algorithm
state tomography
DiVincenzo criteria

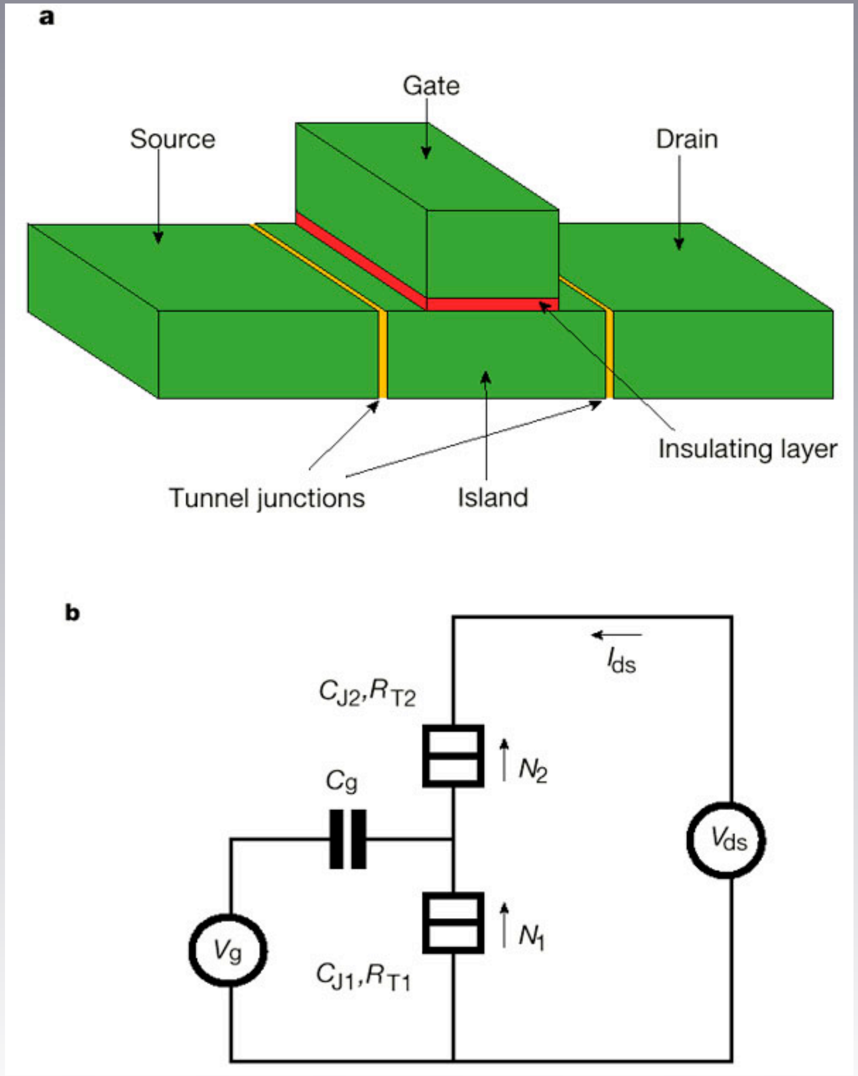
II Superconducting Electronics



Josephson junction
superconductors
tunnel junctions
Josephson equations
SQUID



II Superconducting Electronics



single electron transistor

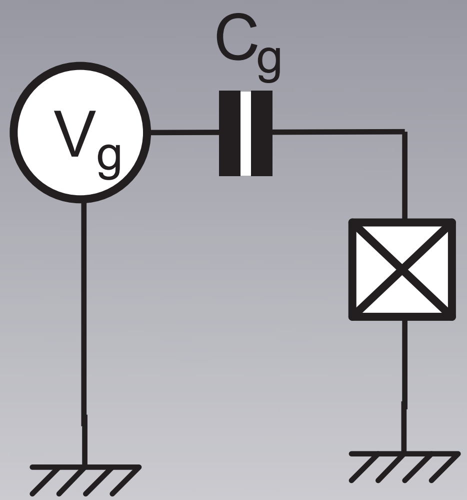
charging energy

Coulomb blockade

amplifying quantum signals

II Superconducting Electronics

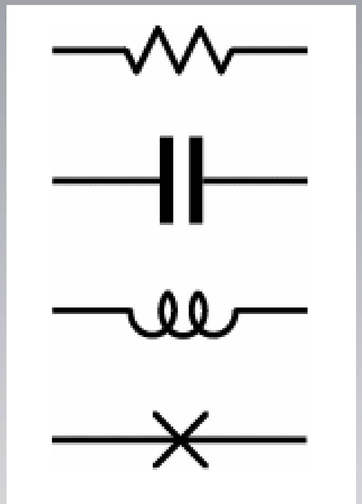
Quantum Circuits



charge and phase are conjugate variables

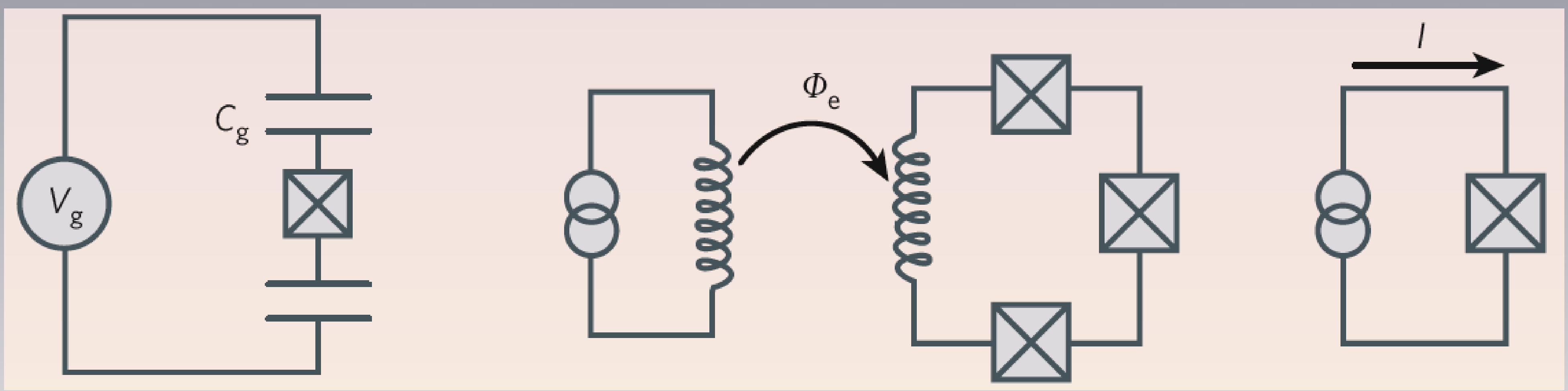
quantization of a circuit

Circuit Elements



II Superconducting Electronics

Superconducting Qubits



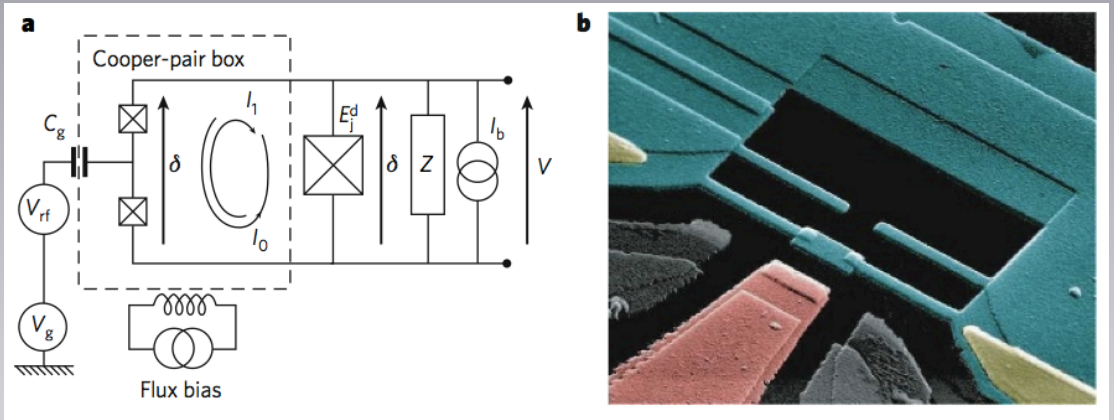
Charge Qubit

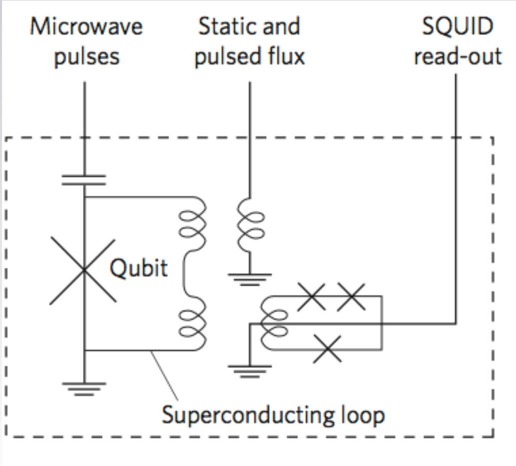
Flux Qubit

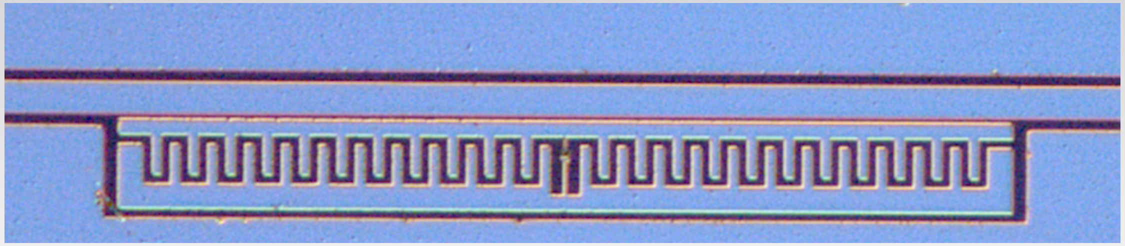
Phase Qubit

II Superconducting Electronics

Qubit Measurement
Qubit (avoiding) Decoherence



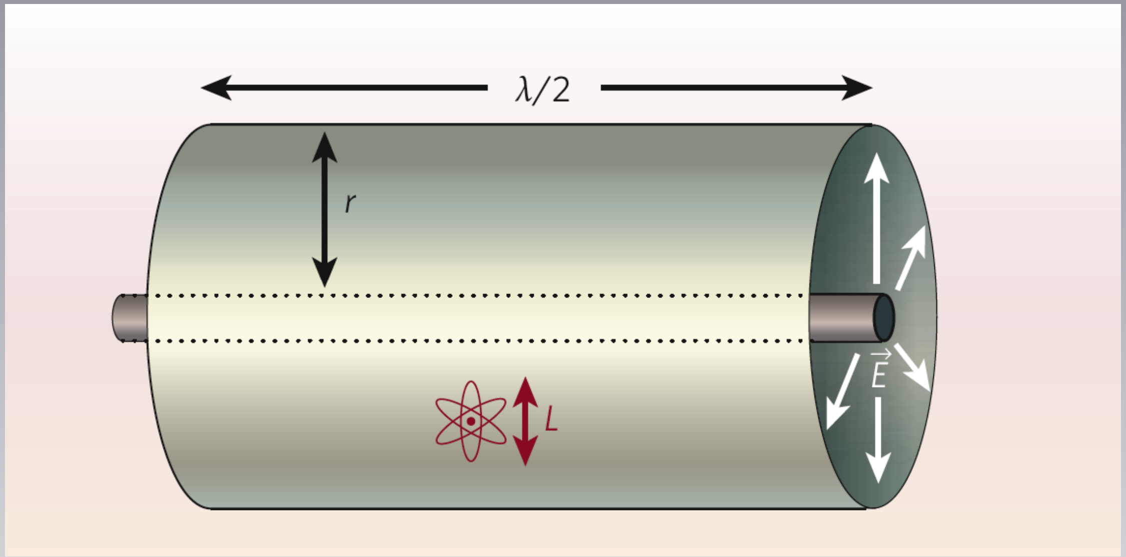


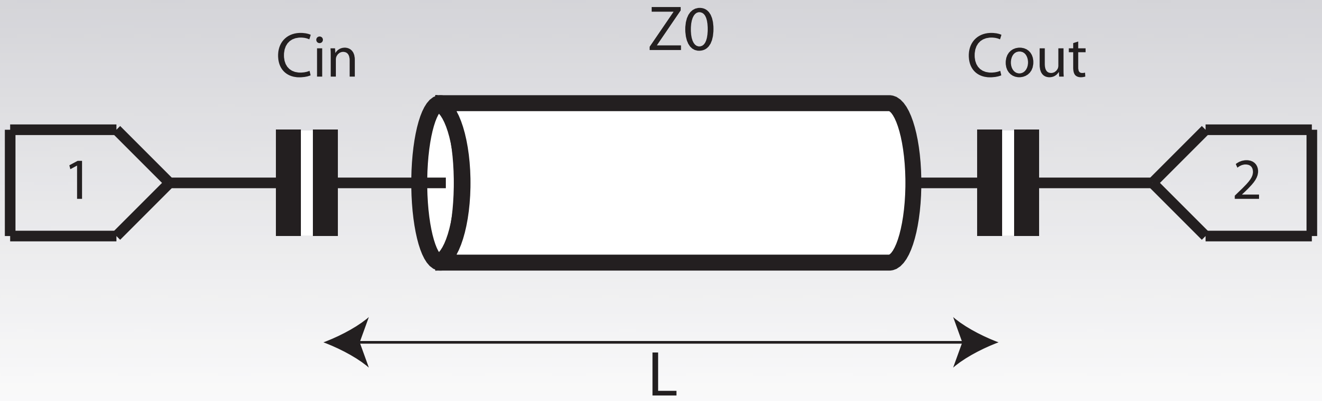


Transmon Qubit

II Superconducting Electronics

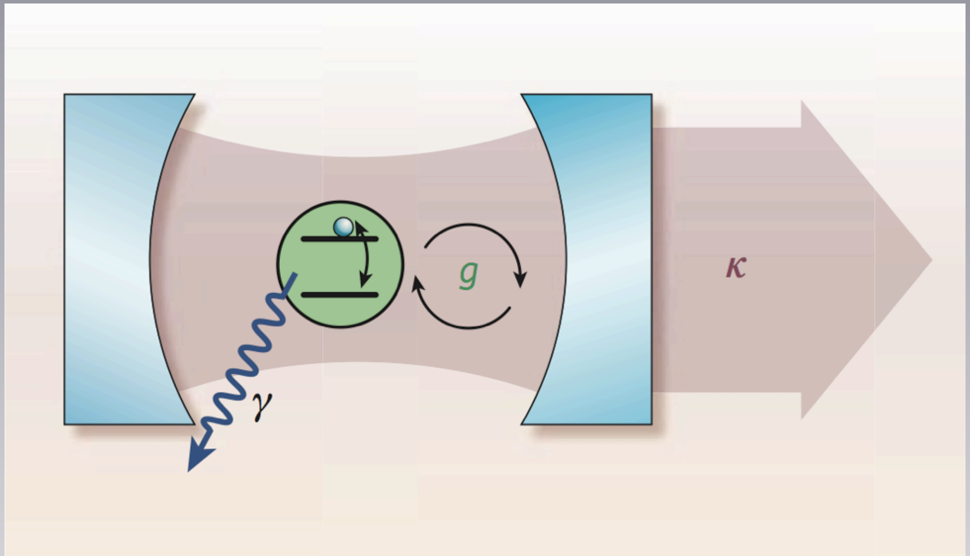
Transmission Line Resonators

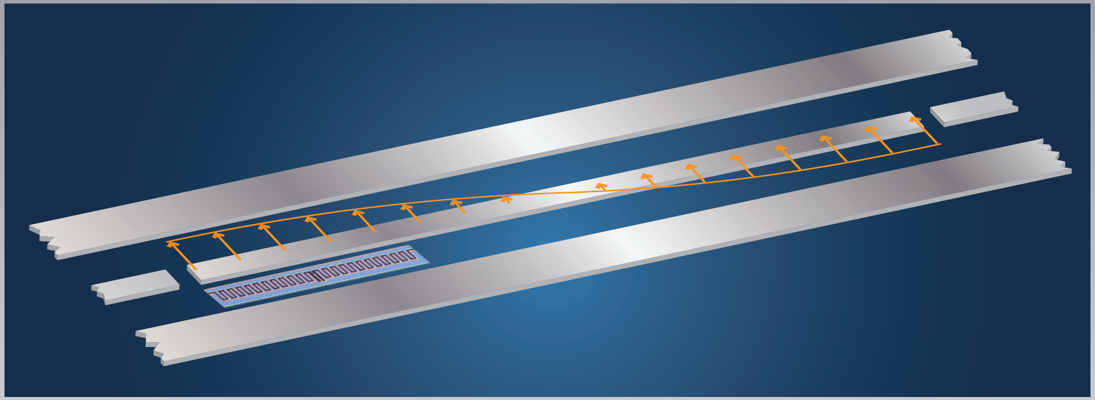




II Superconducting Electronics

circuit cavity QED

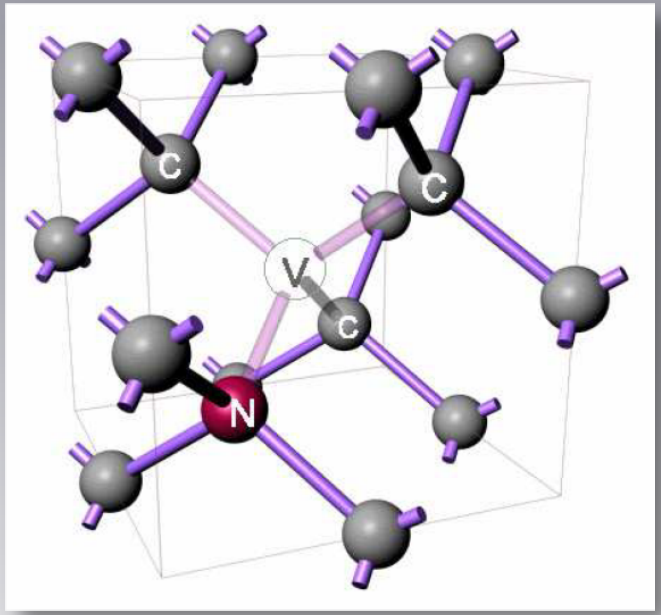


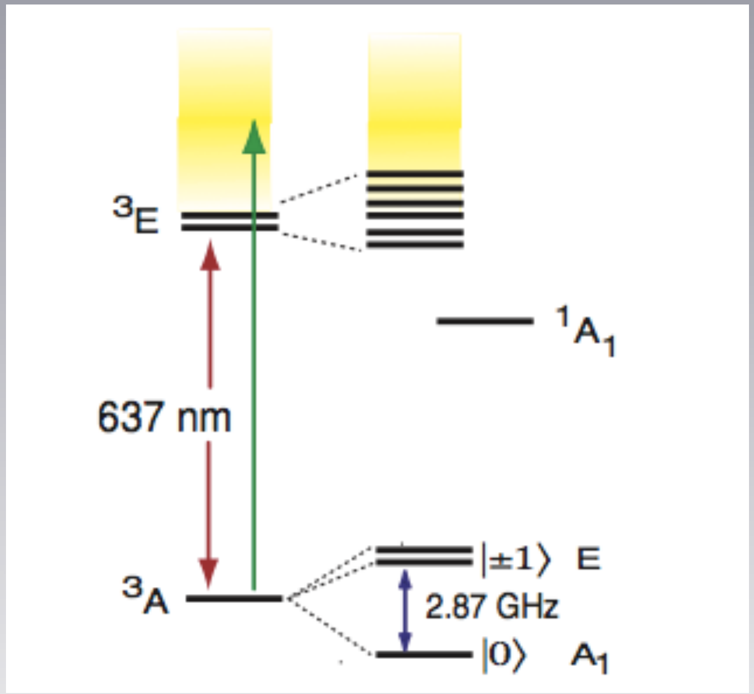


Jaynes-Cummings hamiltonian
vacuum Rabi oscillations
dispersive regime

III Other Solid-State Quantum Systems

Nitrogen Vacancy Color Center





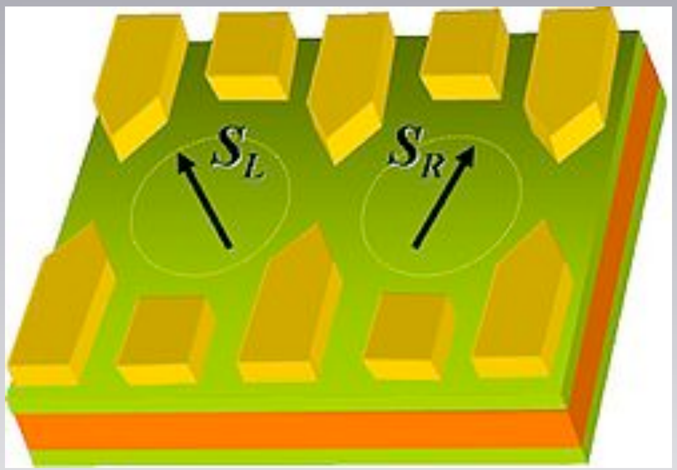
room temperature

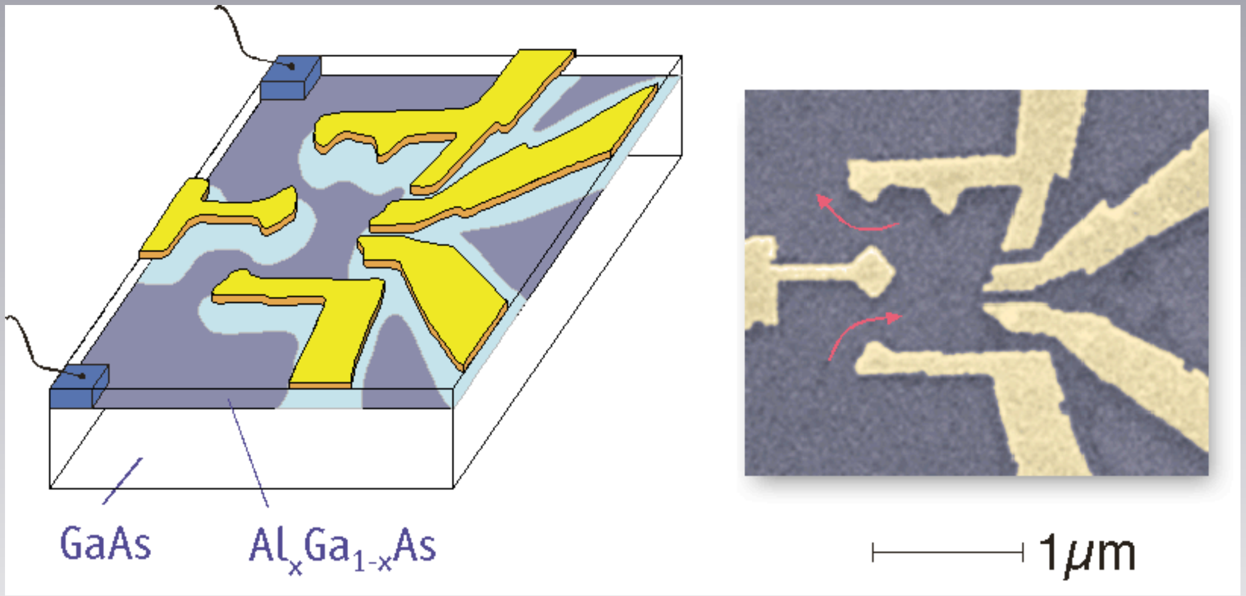
optically detected magnetic resonance (ODMR)

coupling to N nucleus / ^{13}C nucleus

III Other Solid-State Quantum Systems

Semiconductor Quantum Dots



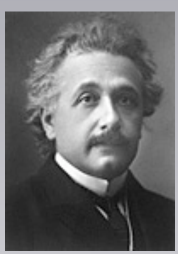
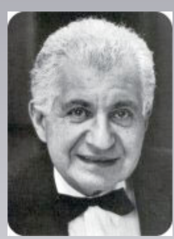
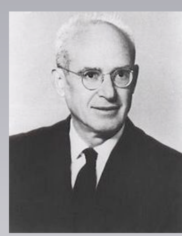
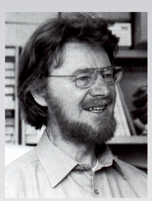


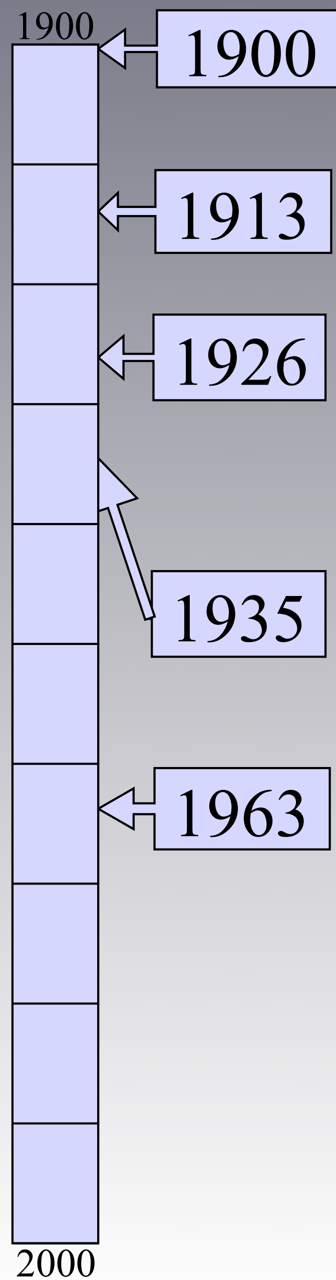
Loss-DiVincenzo proposal

Quantum Physics







1900 Planck: $\hbar$

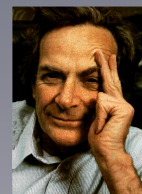
1913 Bohr: model of the atom

1926 Schrödinger/Heisenberg

1935 Einstein/Podolski/Rosen

1963 Bell: inequalities

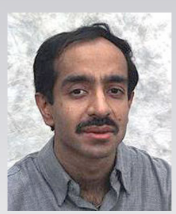
Quantum Computing

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

Problem Set

Problem Set 1 - LV 141.246 QISS - 14.10.2011

1. **Energy Scales** As discussed in the lecture, you can convert energy into temperature, frequency and wavelength via the following relations

$$
\begin{aligned}
E &= k_B T \\
E &= h f \\
\lambda &= \frac{c}{f}
\end{aligned}
$$

Calculate the corresponding values for the following data

(a) Optical light (HeNe laser, red, 632.8nm)

(b) WLAN frequency (2.4 GHz)

(c) Ambient temperature (300 Kelvin)

(d) Ionization energy (He ionization energy 24.58eV)

Consider your results!

Problem Set

2. **MATLAB - Getting Started** MATLAB is very useful tool for dealing with numerical problems, especially handling vectors and matrices. It should be installed on your student computer. You can also purchase it for €13.90 from the ZID `http://www.sss.tuwien.ac.at/sss/mla/`

   (a) Create a vector t with values (0, 0.1, 0.2, ... 10). Calculate $y = e^{t(3i-1/2)}$. Plot the real part of y versus t.

   (b) Enter the following three matrices

$$A = \begin{pmatrix} 0 & i \\ i & 0 \end{pmatrix} \qquad B = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & -i \\ 0 & i & 0 \end{pmatrix} \qquad C = \frac{1}{2} \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{pmatrix}$$

   .

   Are these matrices hermitian (Hint: a matrix is hermitian if $H = H^\dagger$. Therefore calculate $H - H^\dagger$), are they unitary? Calculate trace and eigenvalues of these matrices.

search internet for: MATLAB tutorial