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Introduction to the concepts of nanoscale science

Review of electronic properties: from atoms to bulk

Imaging, manipulation, and spectroscopy at the atomic scale

Confinement of electronic states

Making the nanostructures: top-down and bottom-up approaches

Advances in field-effect transistors (FETs): solid state devices (SSD), 2D-FETs

Quantum transport in 1D, and in 0D (single-electron FET)

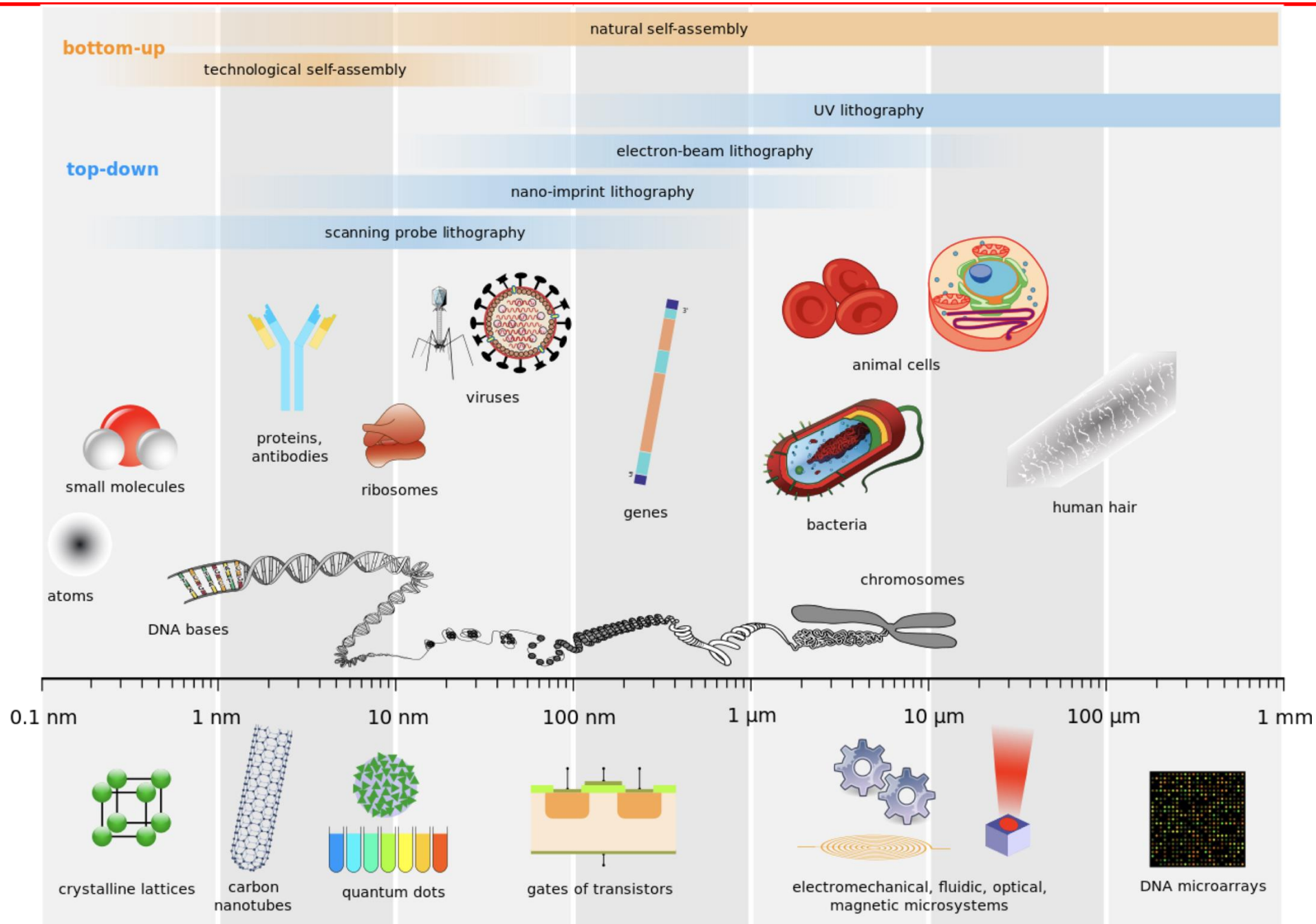
Magnetism at the nanoscale: magnetic data storage (HDD), introduction to spintronics

Throughout the lectures: experimental techniques

Files on Moodle may be updated shortly before the lecture

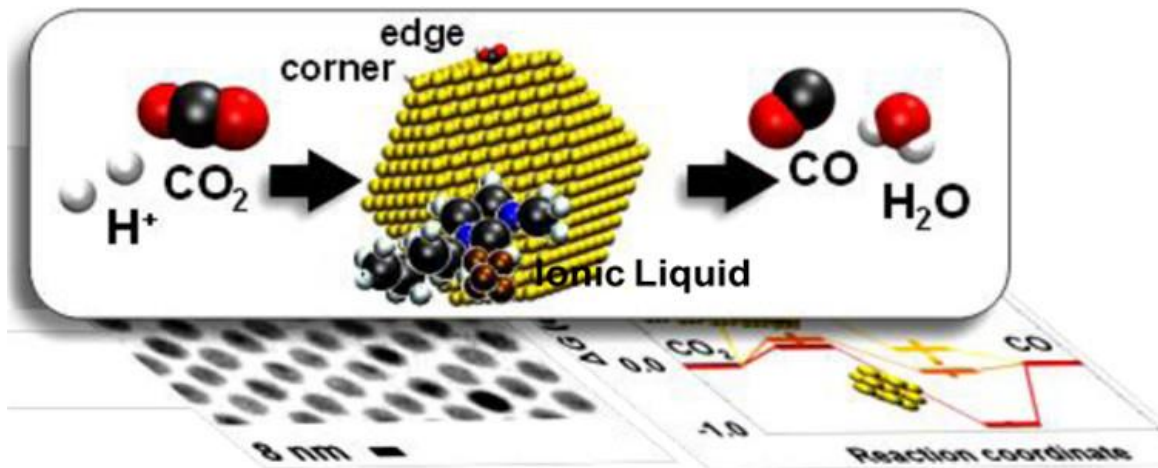


Scales: micro to nano



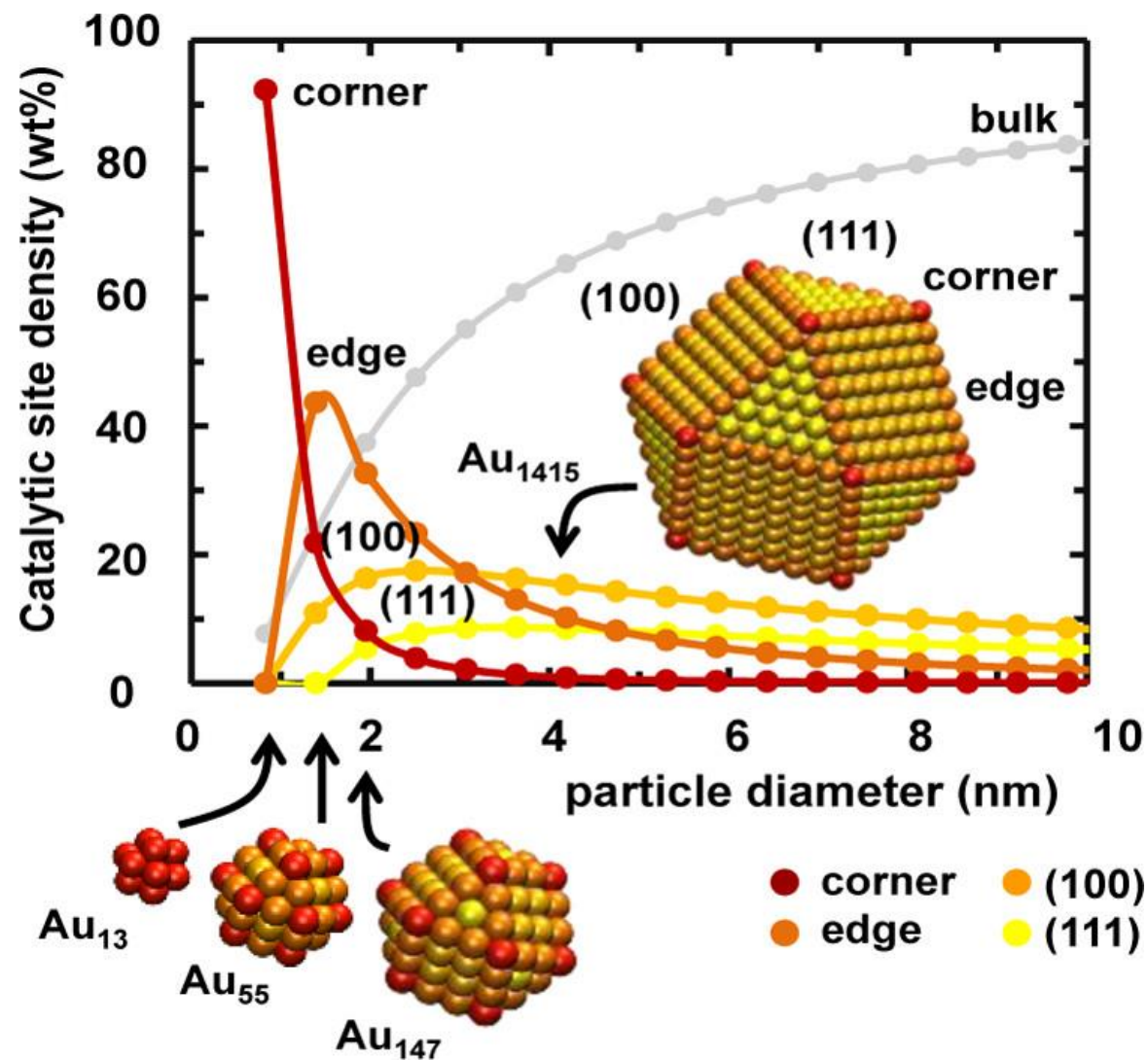


Au nanocrystals



Nanocrystals

- Equilibrium shape?
- Catalytic sites?
- Size dependence?

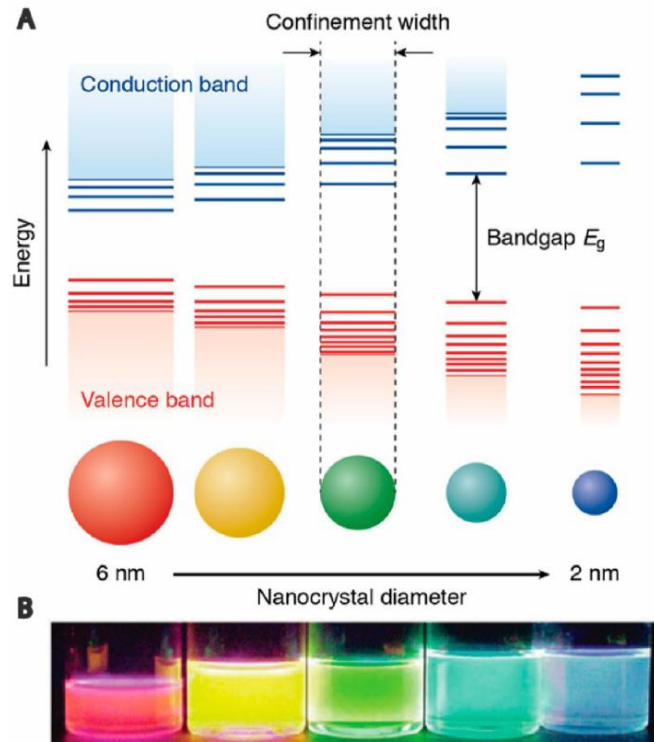


DOI: [10.1021/ja409445p](https://doi.org/10.1021/ja409445p)

J. Am. Chem. Soc. **135**, 16833 (2013)



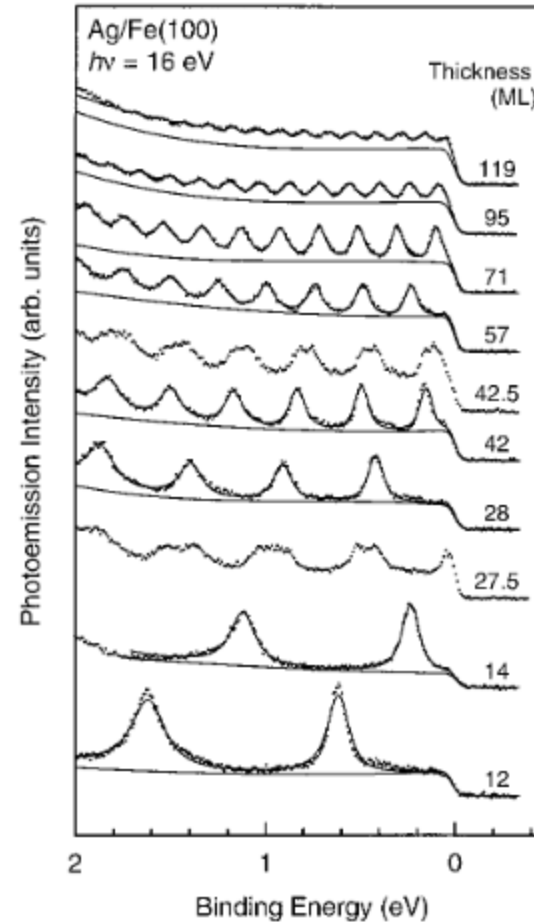
CdSe colloidal nanocrystals (quantum dots)



DOI: [10.1021/acs.jpcllett.7b01640](https://doi.org/10.1021/acs.jpcllett.7b01640)

J. Phys. Chem. Lett. **8**, 4077 (2017)

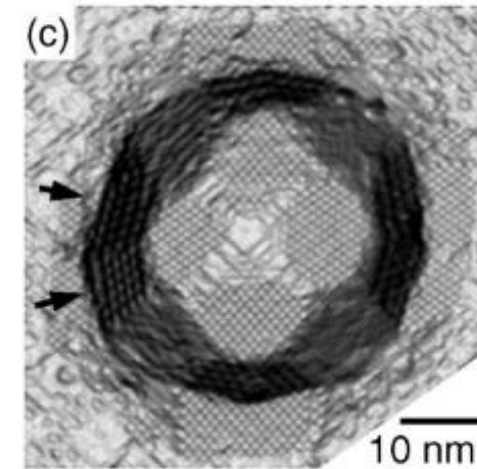
Ag thin films (quantum wells)



DOI: [10.1126/science.283.5408.1709](https://doi.org/10.1126/science.283.5408.1709)

Science **283**, 1709 (199)

Ge/Si(001) dome (quantum dot)

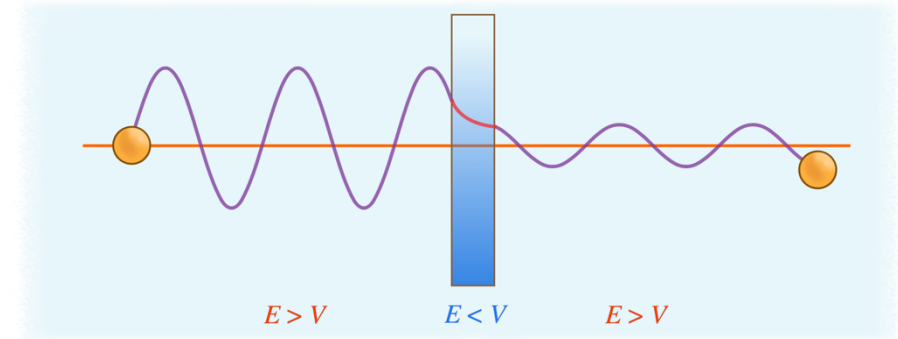
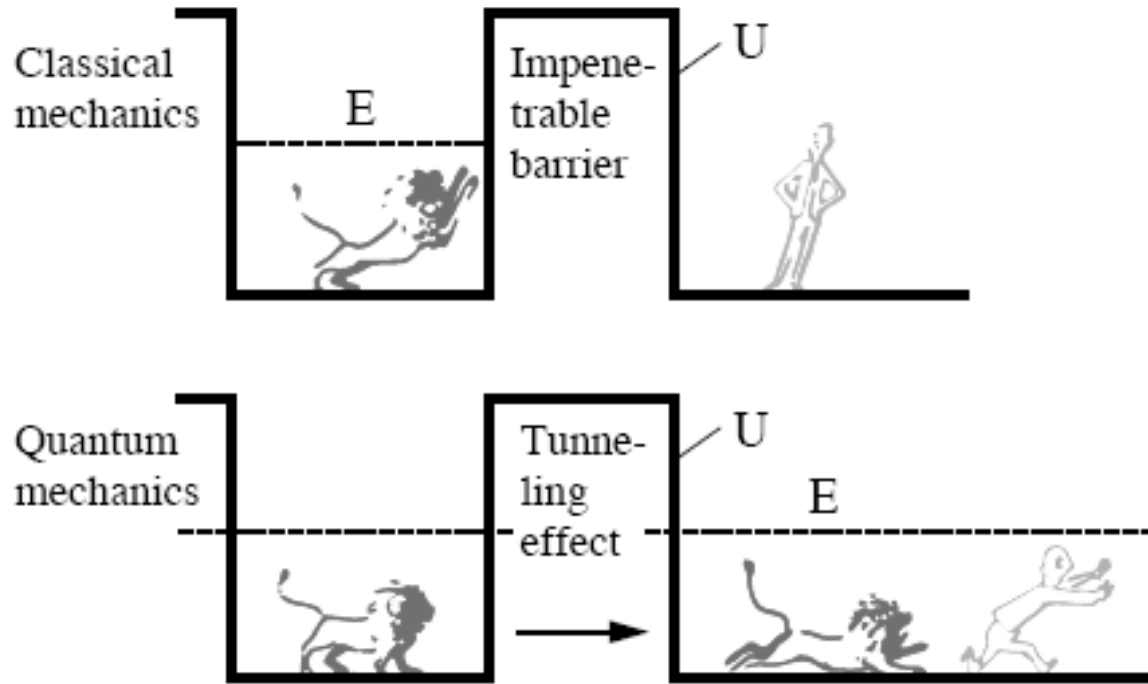
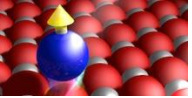


DOI: [10.1103/PhysRevLett.93.216102](https://doi.org/10.1103/PhysRevLett.93.216102)

Phys. Rev. Lett. **93**, 216102 (2004)

Appearance of discrete energy levels

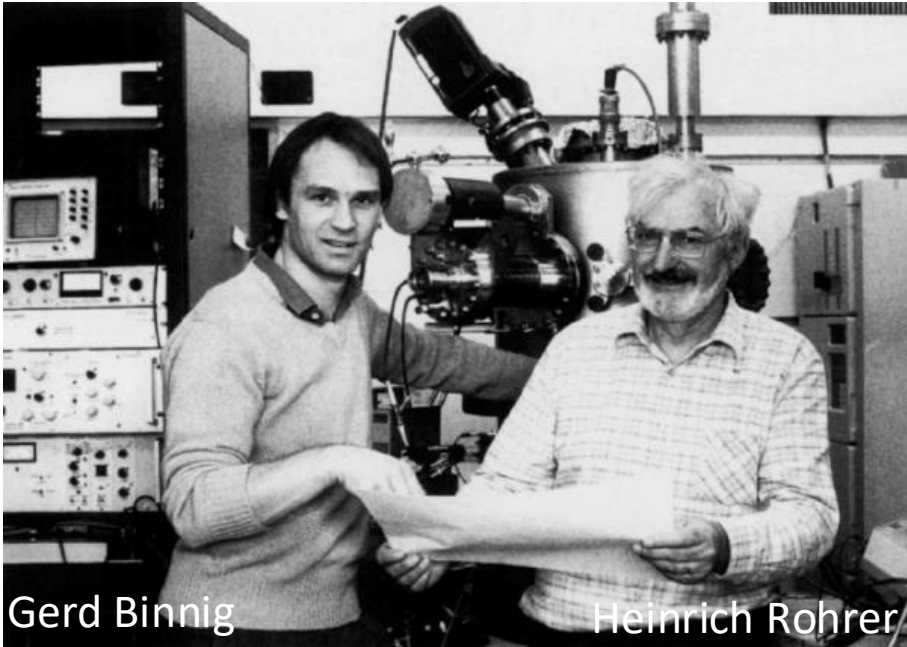
- What are the relevant parameters?
- Dimension dependence (2D, 1D, 0D)?
- Size dependence?
- Material dependence?
- Growth processes?
- Stable shapes for 0D?
- How to observe them?
- Applications?



The difference between classical theory and quantum theory. In quantum mechanics, an electron has a nonzero probability of tunneling through a potential barrier. (After Van Vleck; see Walmsley, 1987.)

Quantum tunneling of electrons

- At what size does it start to be relevant?
- Asset or drawback?



Gerd Binnig

Heinrich Rohrer

IBM Rüschlikon, 1981

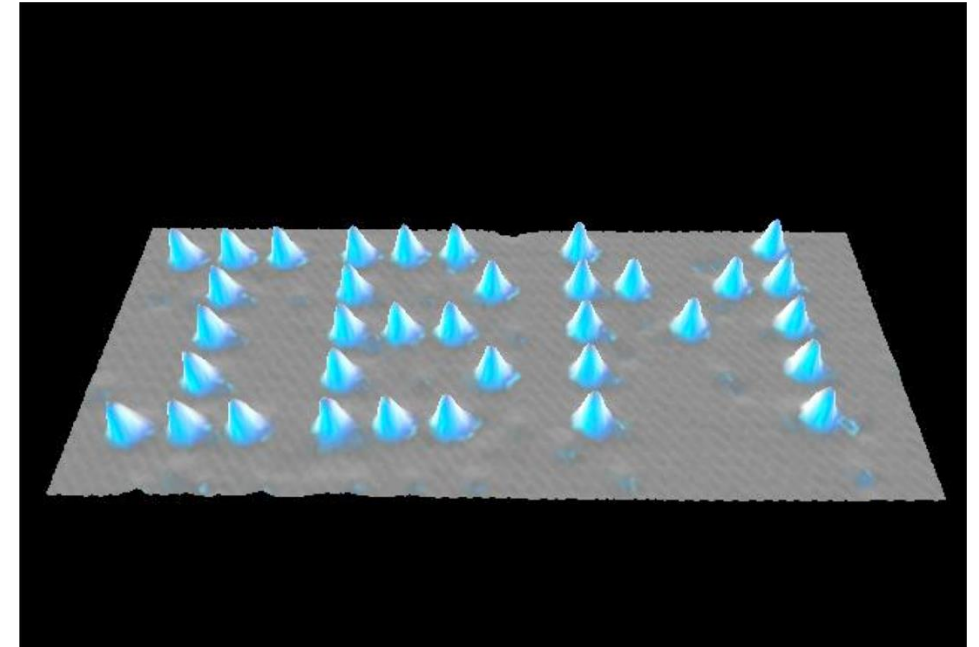
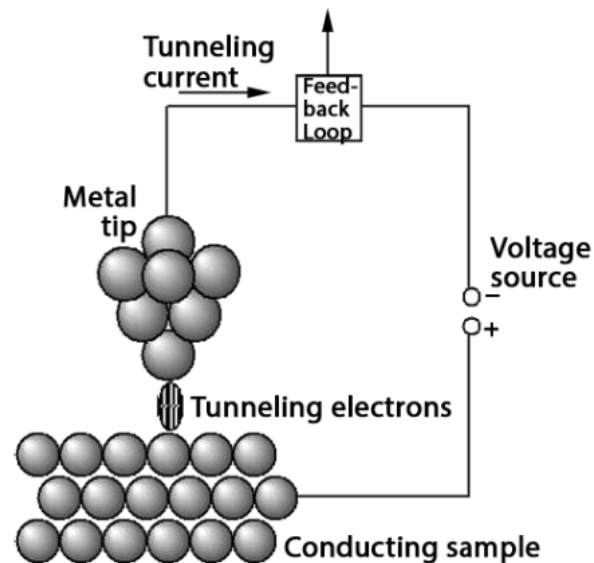
Nobel Prize 1986

[DOI: 10.1103/PhysRevLett.50.120](https://doi.org/10.1103/PhysRevLett.50.120)

G. Binnig et al., Phys. Rev. Lett **50**, 120 (1983)

[DOI: 10.5169/seals-115309](https://doi.org/10.5169/seals-115309)

G. Binnig and H. Rohrer, Helv. Phys. Acta **55**, 726 (1982)

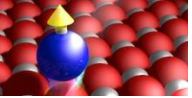


[DOI: 10.1038/344524a0](https://doi.org/10.1038/344524a0)

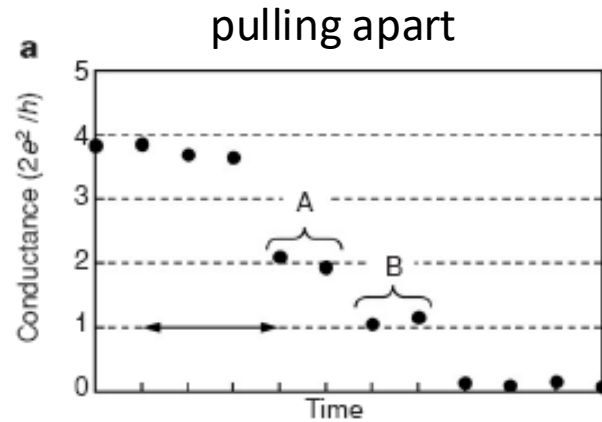
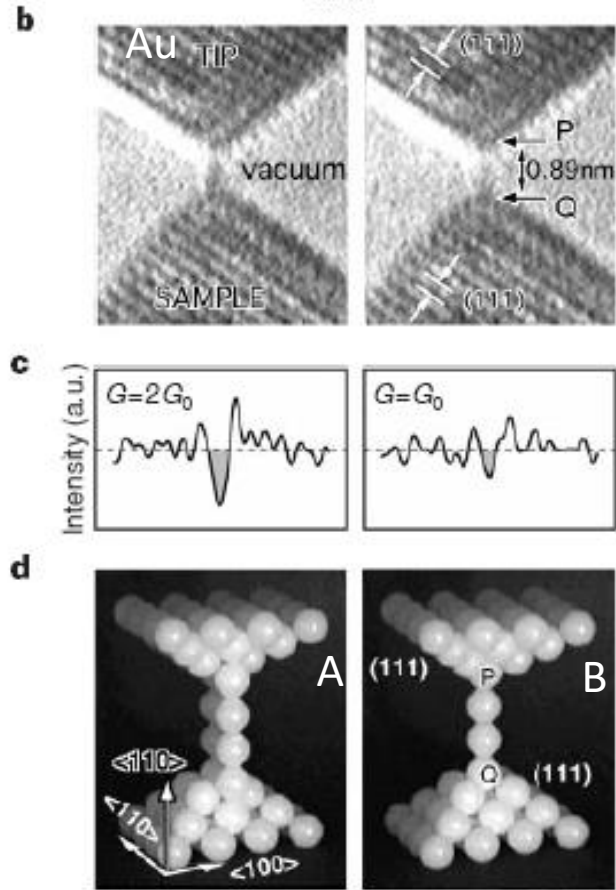
D. Eigler and E. Schweizer, Nature **344**, 524 (1990)

Scanning tunneling microscope

- Lateral and vertical resolution?
- Limitations on materials?
- More than “just” imaging?



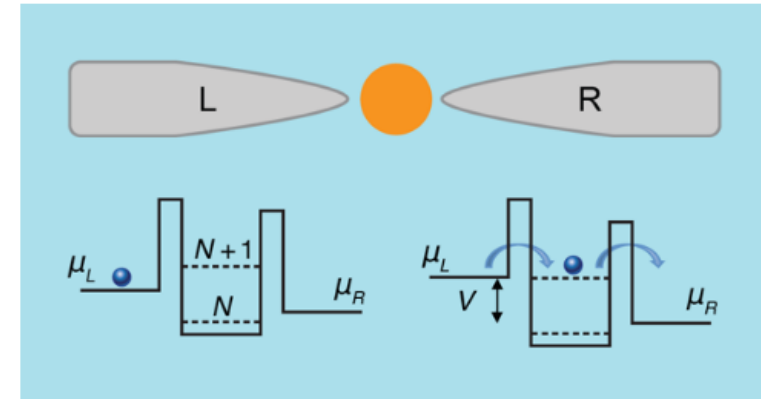
Quantized conductance in nanowires



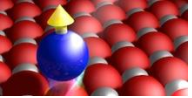
DOI: [10.1038/27399](https://doi.org/10.1038/27399)
 Nature 395, 780 (1998)

- Conditions for observation?
- Experimental realizations?

Coulomb blockade in quantum dots



- Interactions at play?
- Experimental realizations?
- Conditions for observation?
- QD size?
- Applications?



binary information digit (bit)

- any number (or instruction) can be represented by a sequence of bits
- a bit is represented by any mechanism capable of being in two mutually exclusive states (1 and 0), i.e., a switch



<http://zuse.zib.de/relay>
electromechanical relays
1930's - 1950's



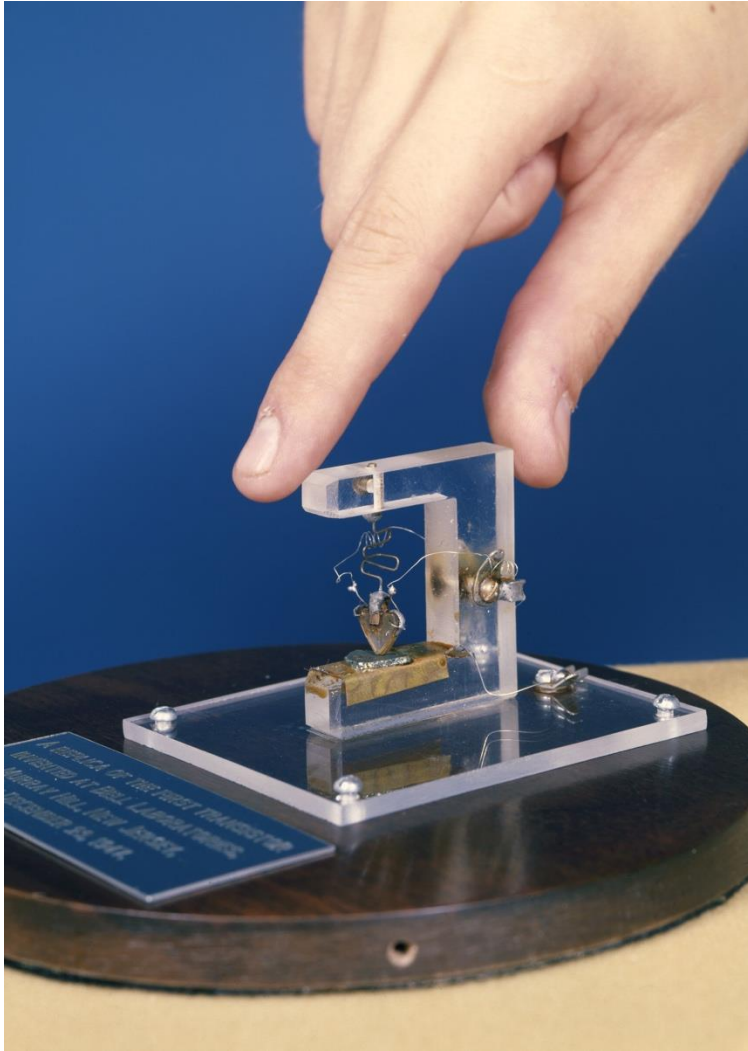
vacuum tubes – triodes
1940's - 1965's



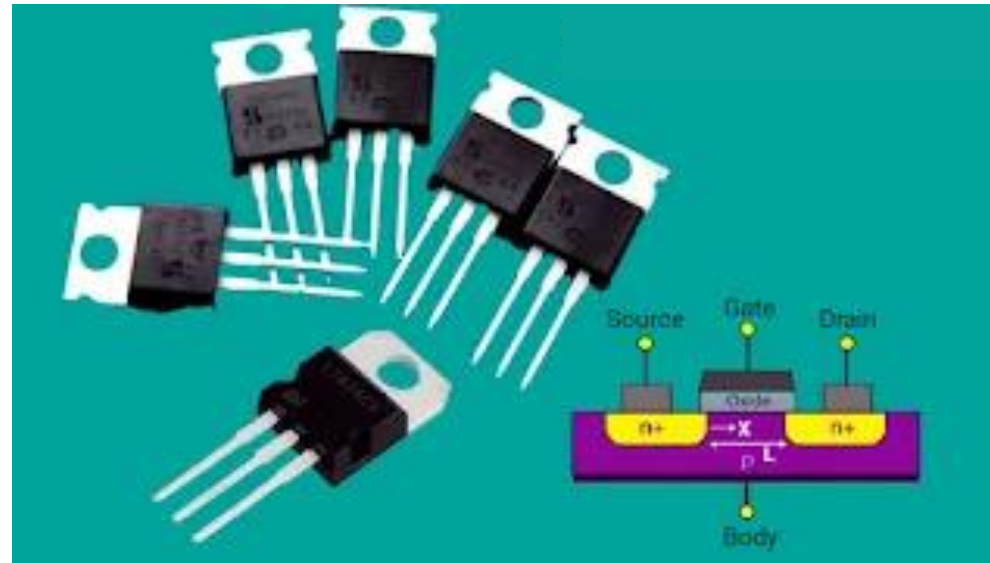
EDVAC
1951



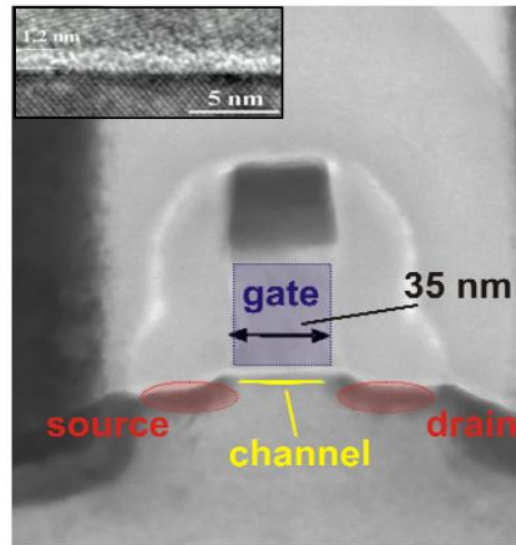
Semiconductors



point contact transistor (1947)



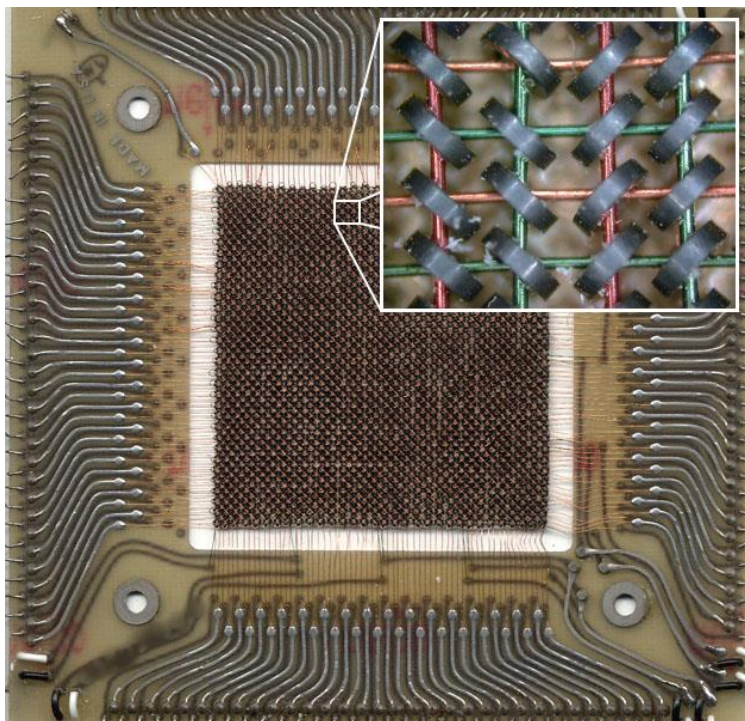
field effect transistor FET (from 1950's)



65nm FET (Intel, 2005)

Field effect transistors

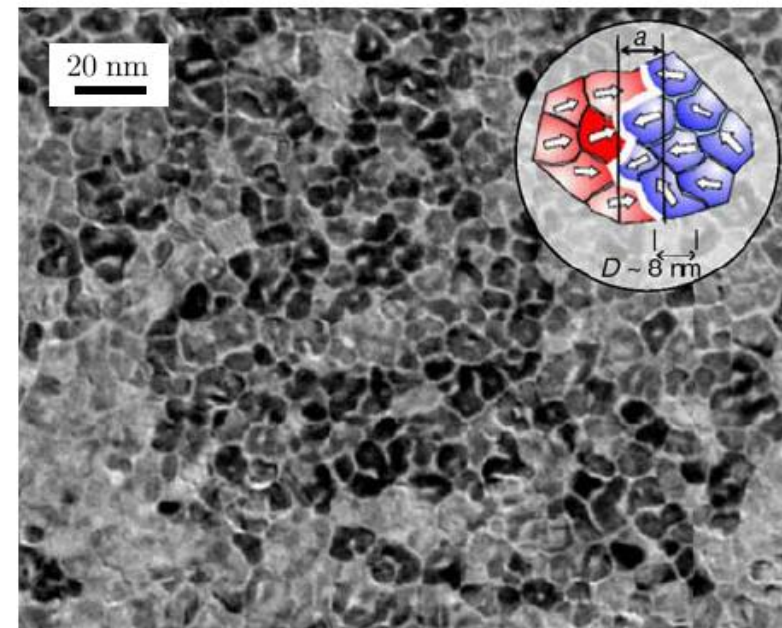
- Critical size and dimensions?
- Fabrication?
- Smart geometries?
- New materials?
- Permanent data storage?



magnetic-core memory (1950's – 1960's)



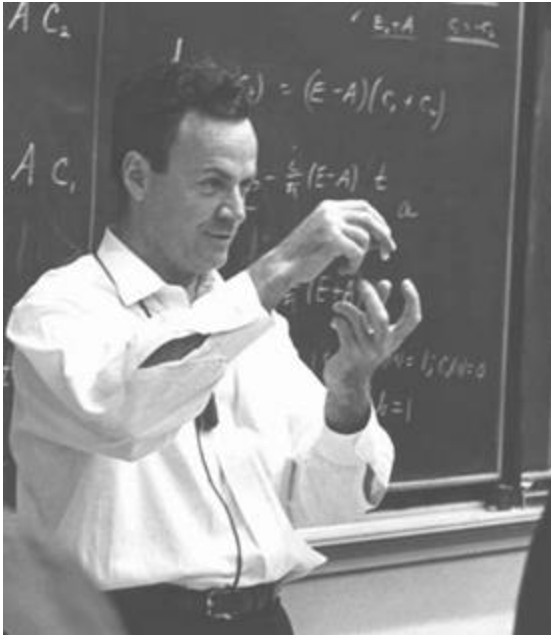
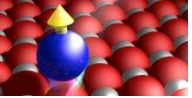
magnetic
hard-disk drive (HDD)
from 1970's



CoCrPt recording layer

Hard disk drive

- Grain size?
- Grain material?
- Magnetic stability?
- Reading and writing?



Richard Feynman

Introduction to Nanoscience
S.M. Lindsay

Chapter 1, Section 1.3
Appendix B