

Structure of matter, matter waves, atomic and molecular interactions. Atomic force microscopy.

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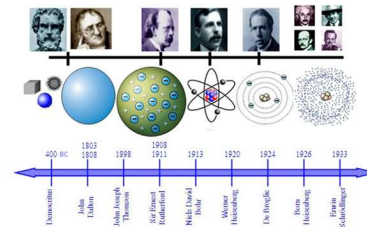


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Department of Biophysics and Radiation Biology,
Semmelweis University

2. October 2019.

Atomic models

Textbook: pages 23-37



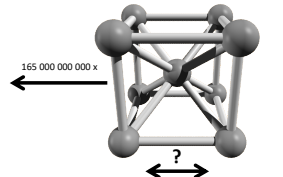
- **Democritus (~400 BC):** proposition of atomic structure („atomos”: indivisible)
- **Dalton (1803):** stoichiometric law: elements consist of identical constituents
- **Thomson (1897):** discovery of electron (cathode rays)
- **Rutherford (1909-1911):** nucleus (nucleons: p^+ and n_0) and electrons
- **Bohr (1913):** discrete energy states

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How are stable structures created/formed?



macroscopic scale: Atomium



nanoworld: face-centered cubic lattice of Fe

Governing principle:

consequence:
DISORDER

repulsive
interaction



attractive
interaction

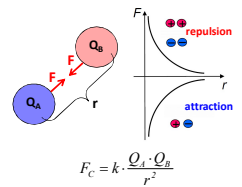
consequence:
ORDER

3

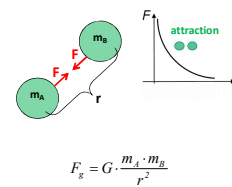
Fundamental interactions in physics

Interaction type	Binding particle	Range (m)	Relative strength
gravitation	every particle	infinite ($\sim 1/r^2$)	10^{-40}
electromagnetic (Coulomb)	charged particles	infinite ($\sim 1/r^2$)	10^{-2}
strong nuclear	nucleons	10^{-15}	1
weak nuclear	every particle	10^{-18}	10^{-13}

Coulomb-interaction

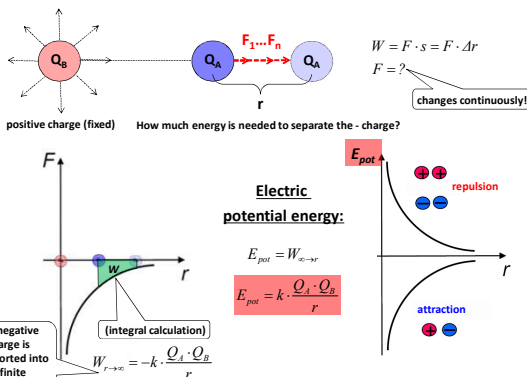


Gravitation



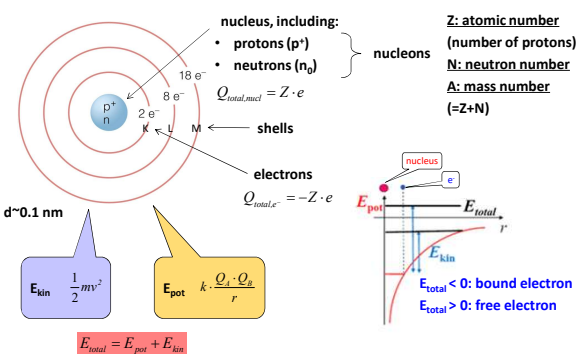
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Electric potential energy (E_{pot})

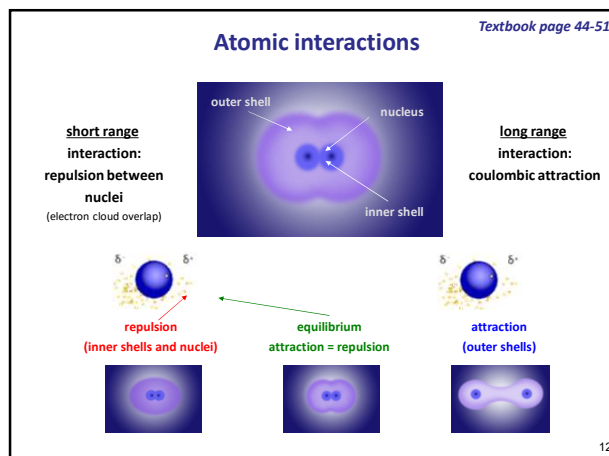
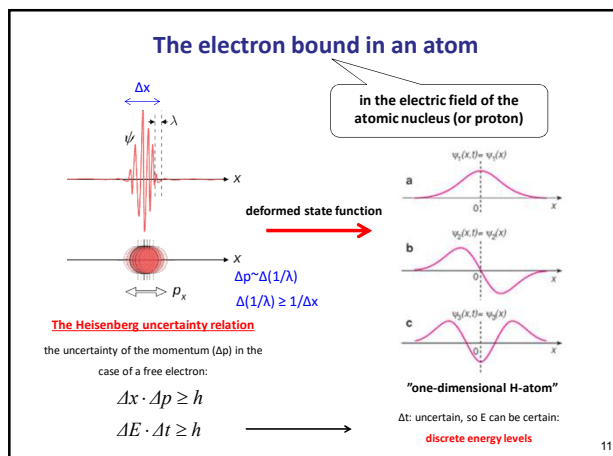
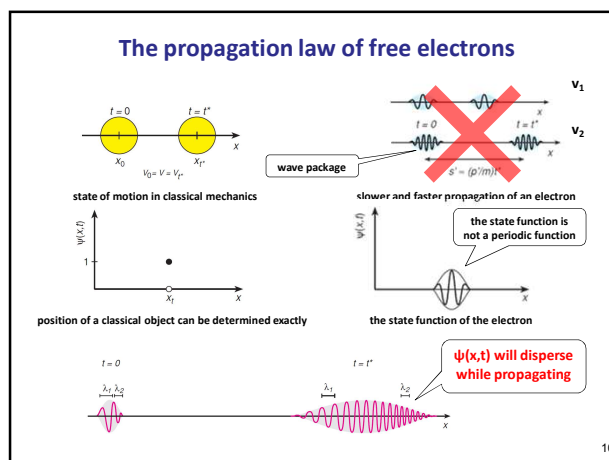
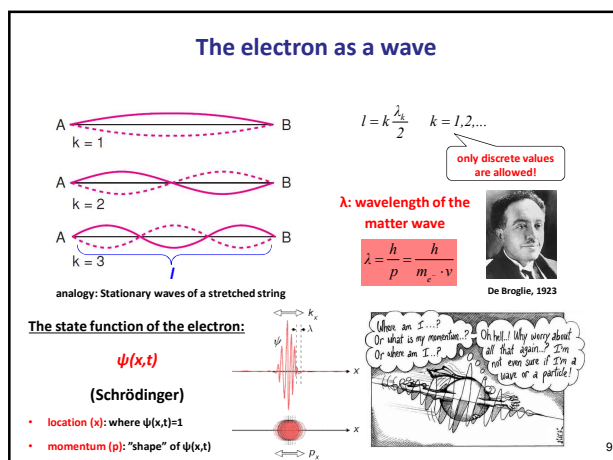
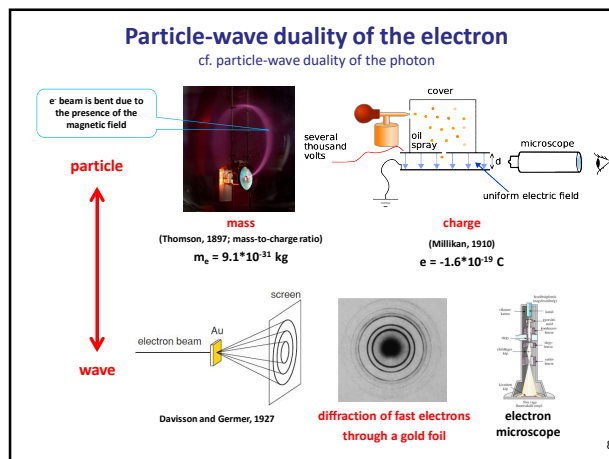
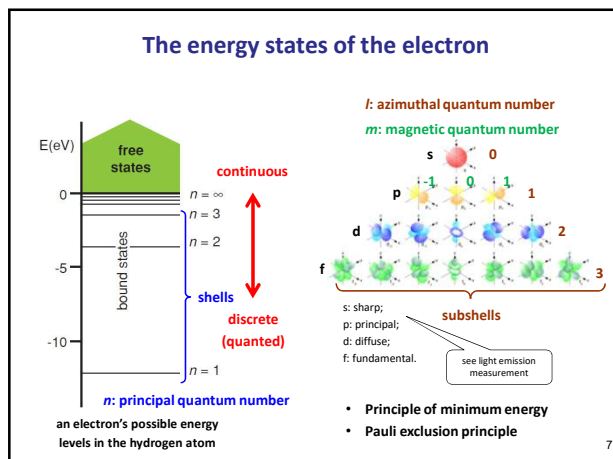


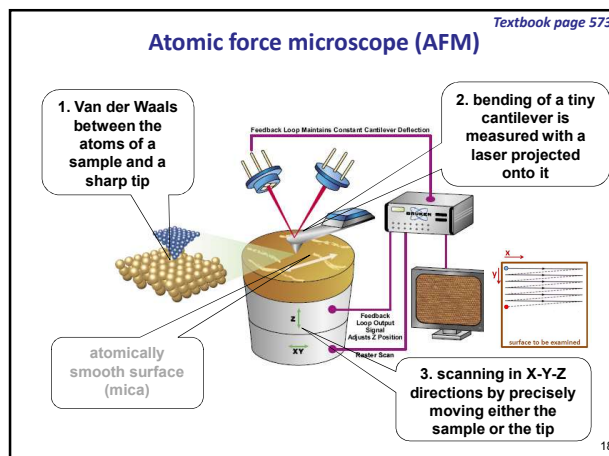
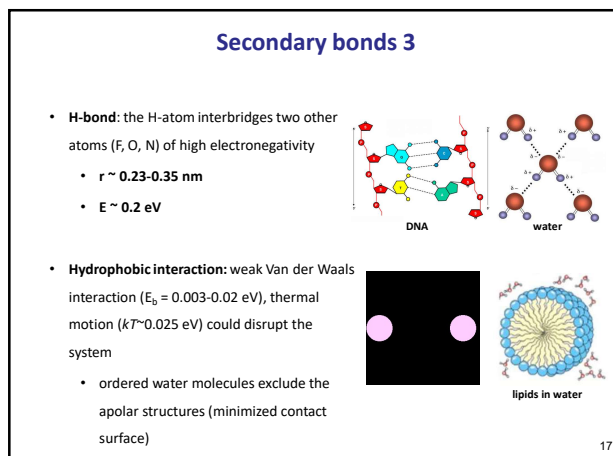
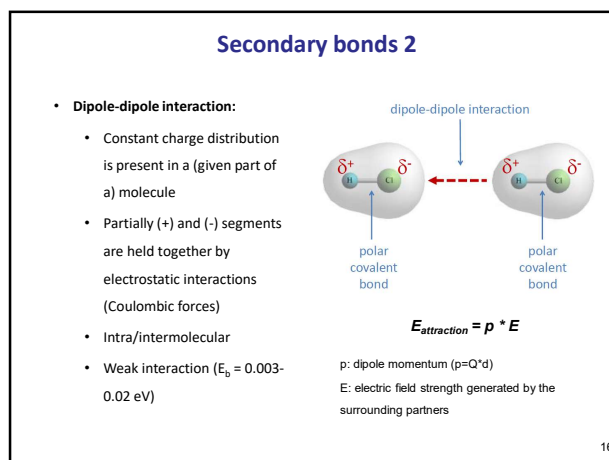
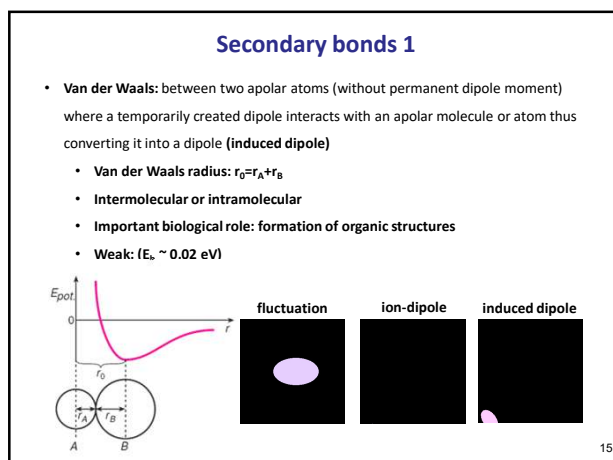
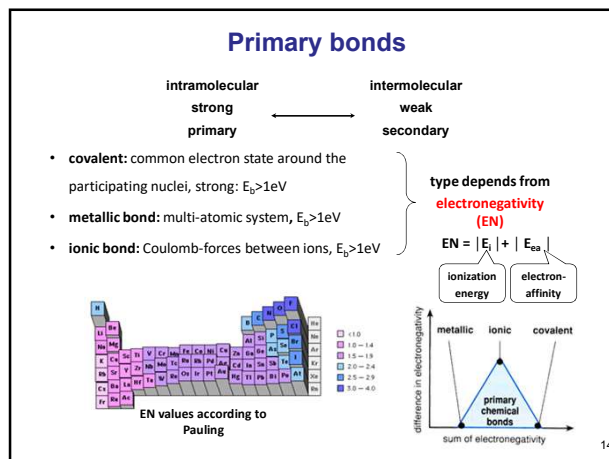
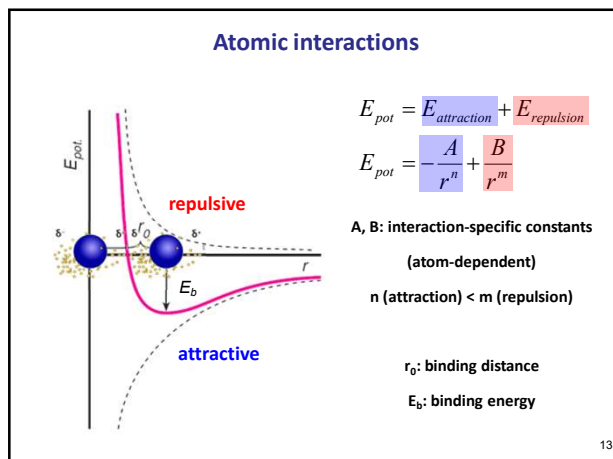
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Structure of the Atom

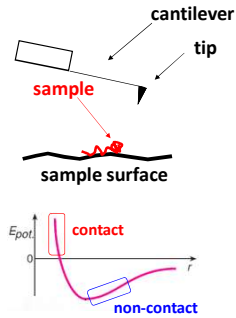


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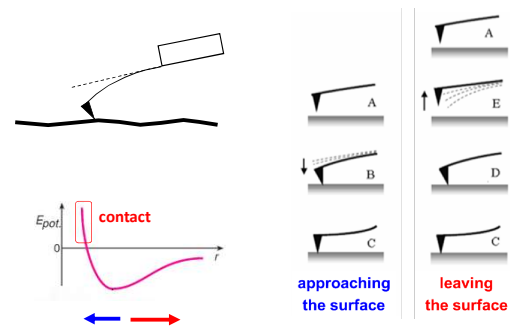
AFM operating modes



- **Contact:** the tip touches the surface, the deflection of the cantilever (i.e. the force exerted on the sample by the tip) is held constant.
 - **Z-feedback** system: deflection is maintained at a constant value (setpoint) by lifting or lowering the cantilever.
 - **topography data** (i.e.: height) in each x,y point is calculated from these Z movements
- **Non-contact:** the cantilever is **oscillated** without contact with the surface: resonant frequency (f_0) and the amplitude of the oscillation changes with surface topography.
 - **Z-feedback:** maintains the amplitude by lifting or lowering the oscillating cantilever.

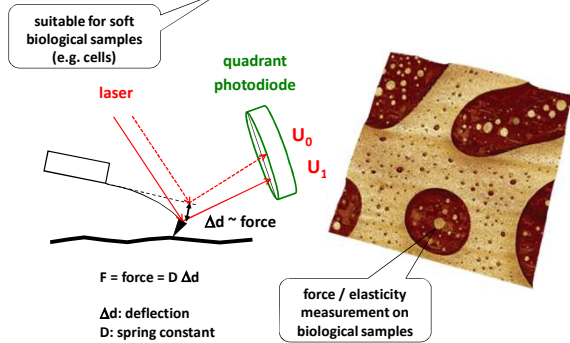
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Contact mode AFM



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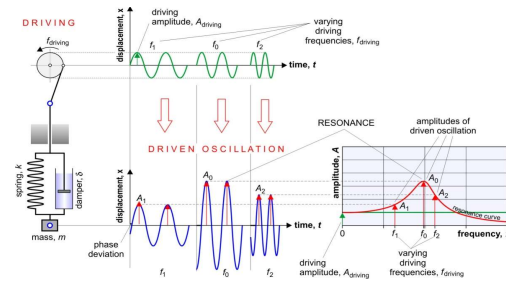
Contact mode AFM



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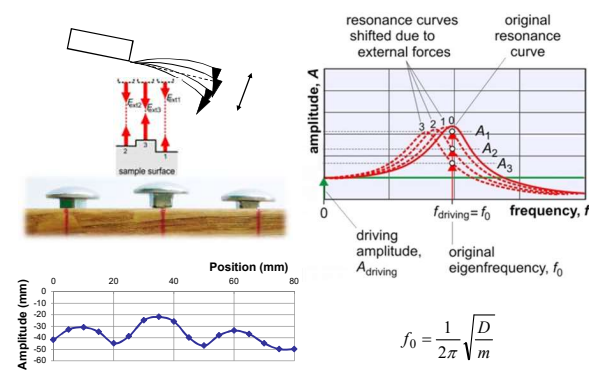
Non-contact/oscillating mode AFM

Resonance: a driven oscillation occurring when the oscillatory system is exposed to a driving force with a frequency close to its eigenfrequency (f_0). Amplitudes may become extremely large.



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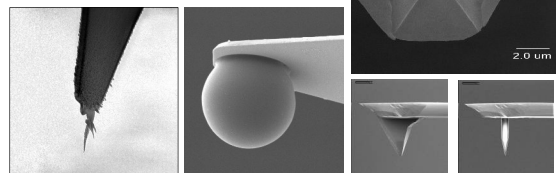
Non-contact/oscillating mode AFM



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Cantilevers

- **Material:** mainly silicon nitride
- **Tip radius:** 0.1 nm- 100 μm
- **Spring constant** $\sim 0.1\text{-}10\text{ N/m}$
- $f_0 \sim 50\text{-}500\text{ kHz}$



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Principle of scanning: piezoelectricity

- direct piezoelectric effect: deformation → voltage
- inverse piezoelectric effect: voltage → deformation
- X, Y, Z axis piezo: e.g. 150 V → 40 μm

0.1-nm-accuracy possible

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AFM - properties

- **Main advantages:**
 - 3D surface profile.
 - Images are collected with ~10 pm vertical and somewhat worse horizontal resolution.
 - Any surfaces (conductors, insulators and semiconductors) can be imaged.
 - Works in ambient air, special gas or in fluid environment as well.
 - Usually does not require fixation or staining of the sample.
 - Biological samples can be examined in their native state and physiological environment.
- **Main disadvantages:**
 - Samples must adhere to a substrate. Surface adhesion may lead to distortion.
 - Slow scan speed.
 - Scan height limited to few microns („the flatter the better”).
 - Scan size limited to few tens of microns.
 - High cost.

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Images recorded in our lab at the Department

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Pentacene molecule

electron current through the tip (STM)

AFM images (tip covered with CO)

Nature Chemistry 1, 597 - 598 (2009)

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Visualizing chemical reactions

Reactant 1: C60H14

Product 2: C60H14

Product 3: C60H14

Product 4: C60H14

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Thank you for your attention!

Modelos Atómicos

- DALTON
- Thomson
- Rutherford
- Bohr
- Sommerfeld
- ??!!?! Schrödinger