

C7790 Introduction to Molecular Modelling

TSM Modelling Molecular Structures

C9087 Computational Chemistry for Structural Biology

Lesson 1

Computational Chemistry (Molecular Modelling)

JS/2022 Present Form of Teaching: Rev3

Petr Kulhánek

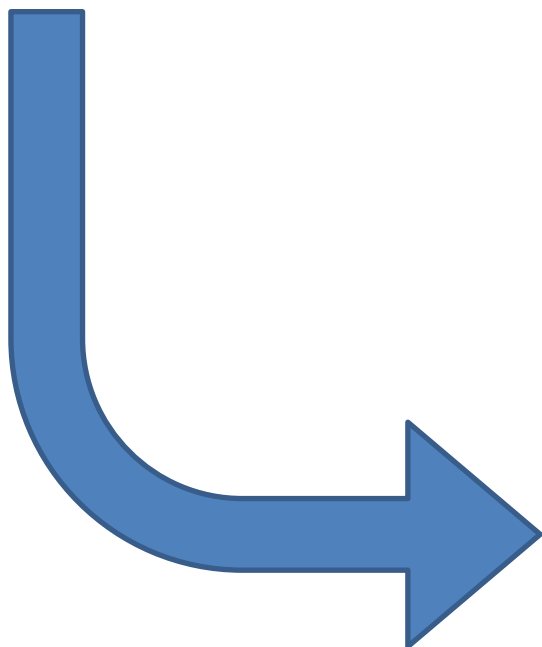
kulhanek@chemi.muni.cz

National Centre for Biomolecular Research, Faculty of Science
Masaryk University, Kamenice 5, CZ-62500 Brno

Computational chemistry

(bio)chemical problem
(behavior of the chemical system at
the macroscopic level)

experiment



molecular nature
(behavior of the chemical system at
the microscopic level)

Computational chemistry

(bio) chemical problem
(behavior of the chemical system at
the macroscopic level)

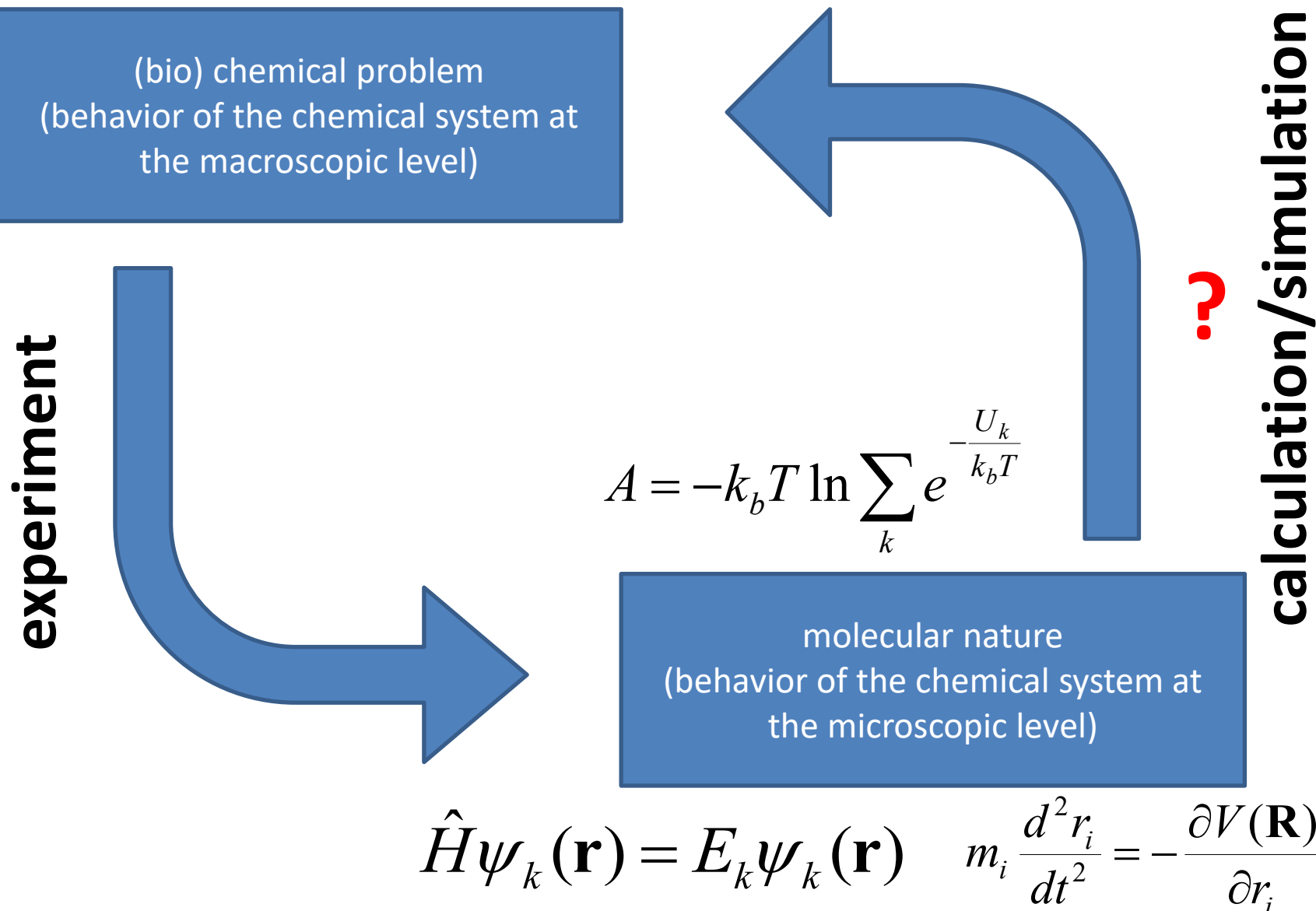
experiment

$$A = -k_b T \ln \sum_k e^{-\frac{U_k}{k_b T}} \quad \text{and more}$$

molecular nature
(behavior of the chemical system at
the microscopic level)

$$\hat{H}\psi_k(\mathbf{r}) = E_k\psi_k(\mathbf{r}) \quad m_i \frac{d^2 r_i}{dt^2} = -\frac{\partial V(\mathbf{R})}{\partial r_i}$$

Computational chemistry



Reality vs Simulation

Is it possible to accurately simulate the reality around us?

Task I

Is it possible to accurately simulate the reality around us?

How many molecules does 180 mL of water contain at room temperature?

How much computer memory will be needed to store the position information of all atoms, including their velocities, using real numbers with single precision?

single precision real number = 4 Bytes

Task II

Is it possible to accurately simulate the reality around us?

How much machine time does 1 s long simulation with the development of the molecular system (H_2O) take?

- The fastest molecular motion in H_2O is the vibration of OH bonds.
- What is the period of this vibration (Use NIST Chemistry WebBook)?
- Each period needs to be discretized by at least 10 frames (snapshots) (see Molecular Dynamics later).
- Computation of each frame takes approximately 1 ms of computer time.

Reality vs Simulation

Is it possible to accurately simulate the reality around us?

Why?

- incomplete theory
- insufficient performance of current and future (?) computers

Unfortunately, no :-)

Solution ...

- use **approximation** for solution of problems using the available computing capacity



Reality vs Simulation

Is it possible to accurately simulate the reality around us?

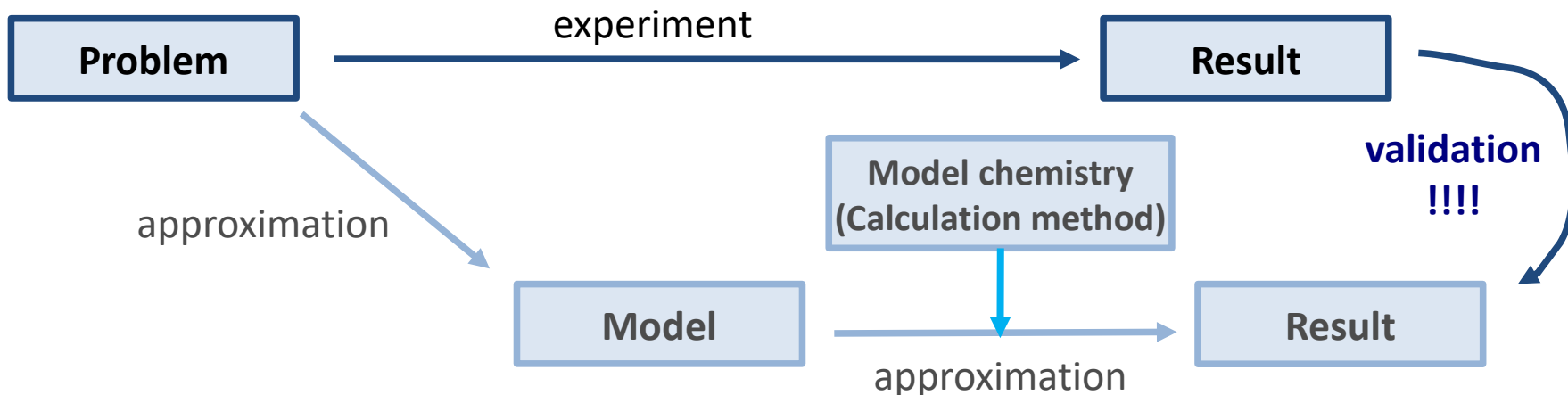
Why?

- incomplete theory
- insufficient performance of current and future (?) computers

Unfortunately, no :-)

Solution ...

- use **approximation** for solution of problems using the available computing capacity



Reality vs Simulation

Is it possible to accurately simulate the reality around us?

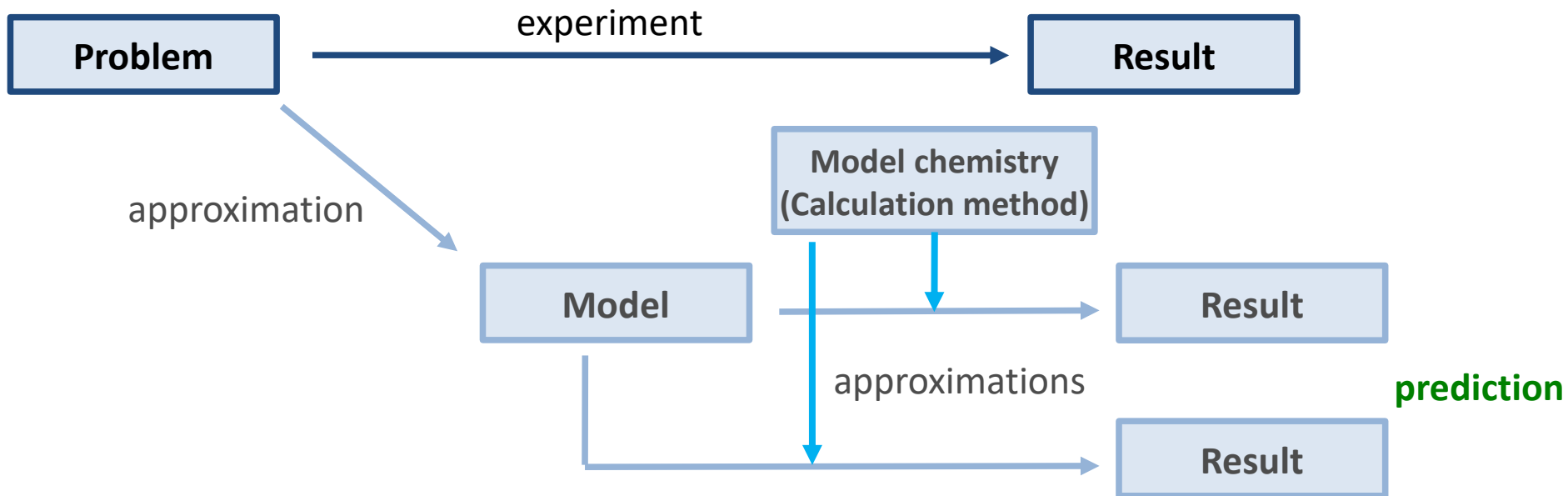
Why?

- incomplete theory
- insufficient performance of current and future (?) computers

Unfortunately, no :-)

Solution ...

- use **approximation** for solution of problems using the available computing capacity



Experimental sources for validation

Comparison of predicted structures with experimental structures

- 3D structure (X-ray, docking)
- shape (cryogenic electron microscopy)
- geometric parameters
- distances (NMR)
- radial distribution function (X-ray scattering, neutron scattering)

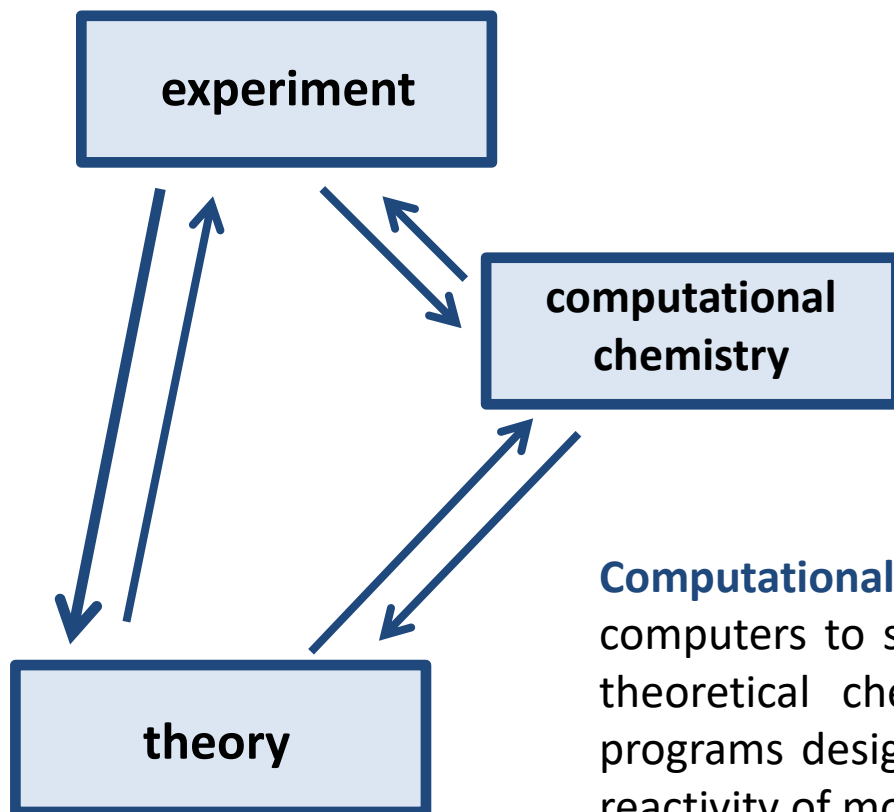
Properties of molecules

- electron spectra (UV/VIS spectroscopy)
- vibrational spectra (IR spectroscopy)
- dipole moment
- diffusion coefficient
- chemical shifts, spin-spin interaction constants (NMR)

Comparison of calculated and experimental thermodynamic and kinetic data

- enthalpy (isothermal titration calorimetry - ITC)
- entropy (ITC)
- free energy (Gibbs, Helmholtz) (ITC, kinetic measurements)

Computational chemistry

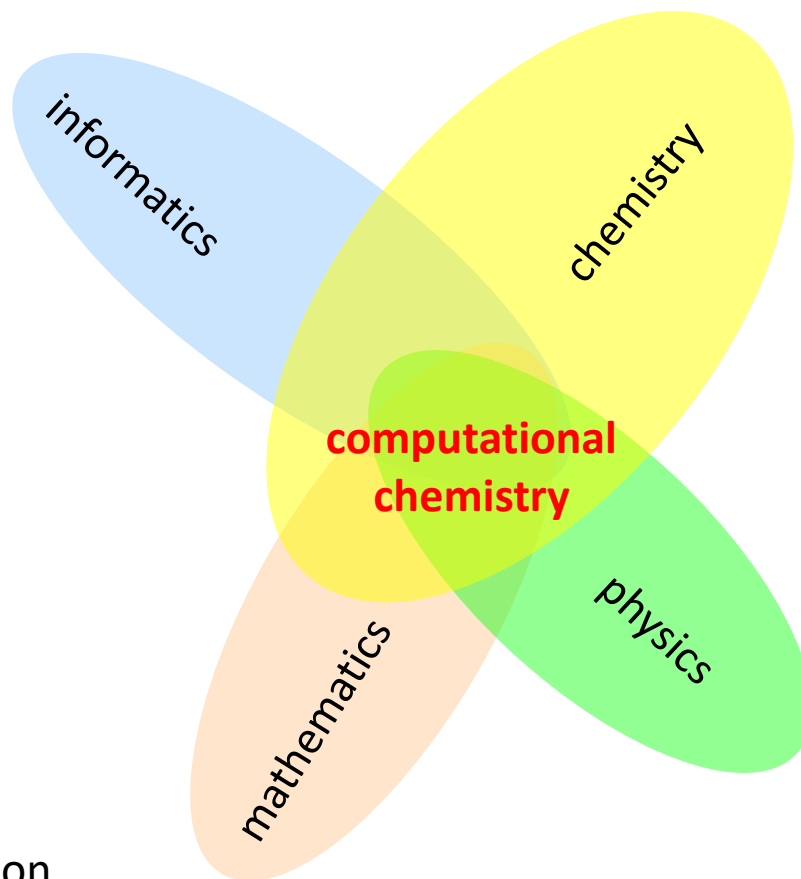


Computational chemistry is a branch of chemistry that uses computers to solve chemical problems. It uses the results of theoretical chemistry implemented in powerful computer programs designed to calculate the structure, properties and reactivity of molecules and solids.

[http:// www.wikipedia.org](http://www.wikipedia.org)

Multidisciplinary discipline

algorithms, CPU / GPU,
cluster / grid,
symbolic calculations

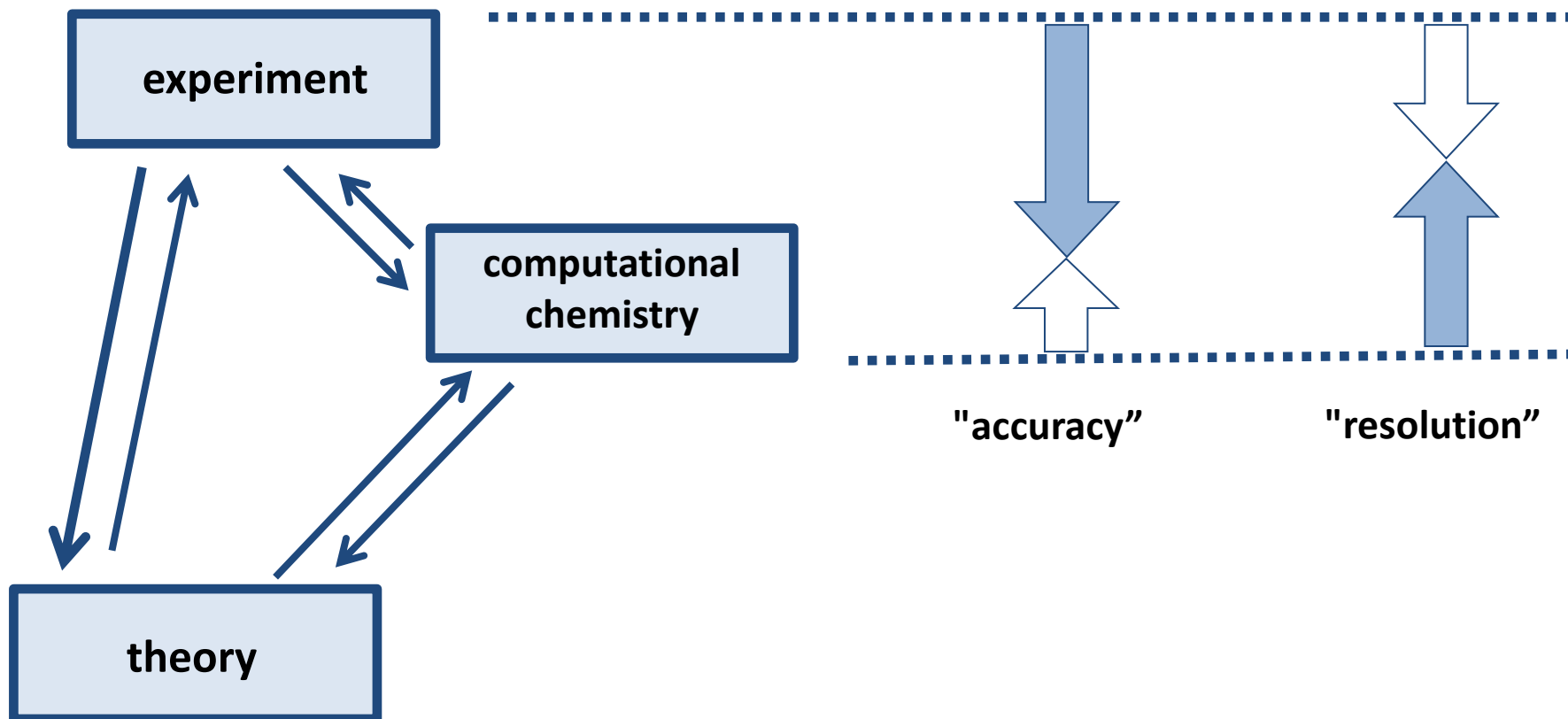


(bio)chemical problems,
experiments,
verification

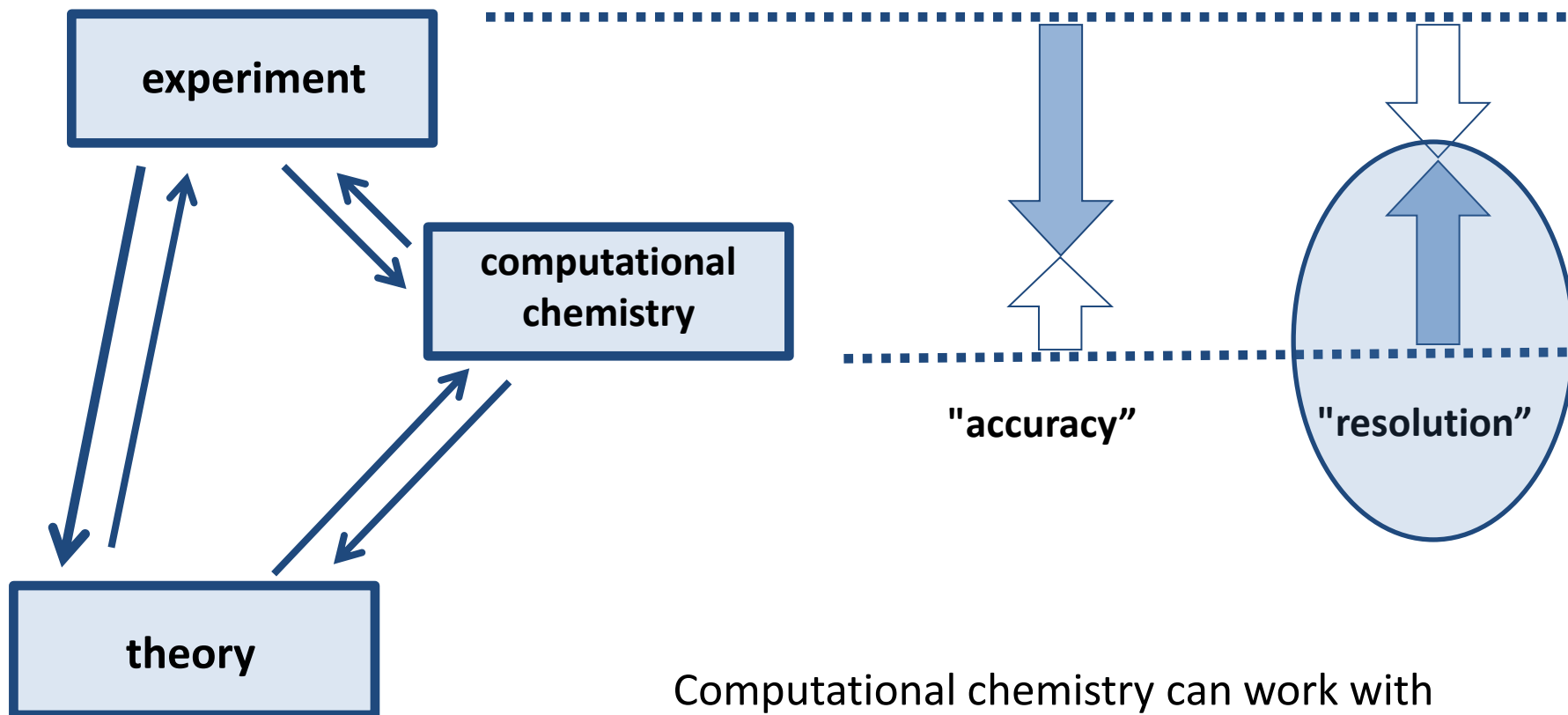
analytical solution,
numerical solutions,
approximation

theory, approximation

Importance of computational chemistry

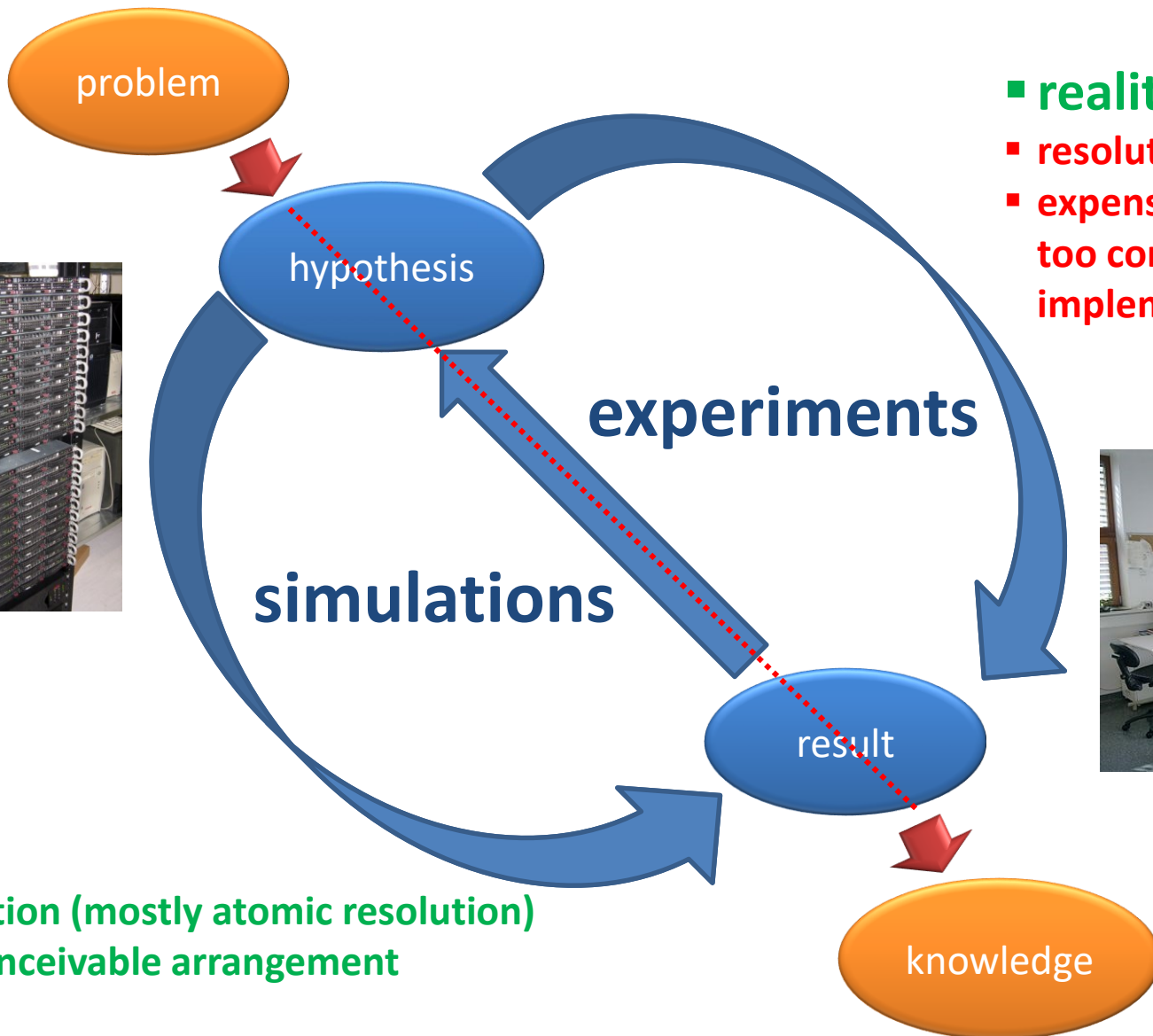


Importance of computational chemistry



Computational chemistry can work with
single atom resolution.

Experiment vs simulation



- reality around us
- resolution
- expensive, dangerous, too complicated to implement



- resolution (mostly atomic resolution)
- any conceivable arrangement
- model

Summary

Computational chemistry (molecular modelling):

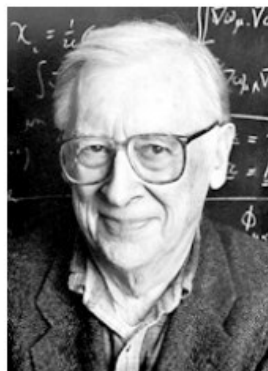
- it is an **interdisciplinary** scientific discipline combining current knowledge of physics, chemistry, mathematics and computer sciences for computational study of **structure, properties, and reactivity** molecular systems
- it uses **approximate** models and calculation procedures
- it requires **verification/calibration** of employed models and computational procedures against experimental data
- it can reach both **qualitative (mostly) and quantitative** results (according to models used)
- it typically employs models with **atomic resolution**

During the lecture we will get acquainted with methods enabling the study of systems containing up to **1,000,000 atoms** in the time scale **a few microseconds**.

Nobel Prize in Chemistry 1998/2013



Walter Kohn



John A. Pople



© Harvard University
Martin Karplus



Photo: © S. Fisch
Michael Levitt



Photo: Wikimedia
Commons
Arieh Warshel

The Nobel Prize in Chemistry 1998 was divided equally between

Walter Kohn for his development of the **density-functional theory** and **John A. Pople** for his development of **computational methods in quantum chemistry**

Development of Multiscale Models for Complex Chemical Systems

http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1998/
http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2013/