भारतीय सांकेतिक विज्ञान संस्थ हैदराबाद
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Biomolecular Simulation BT2123

Lecture 1 : Introduction

Himanshu Joshi 02 January 2023

भारतीय सांकेतिक विज्ञान संस्थ हैदराबाद
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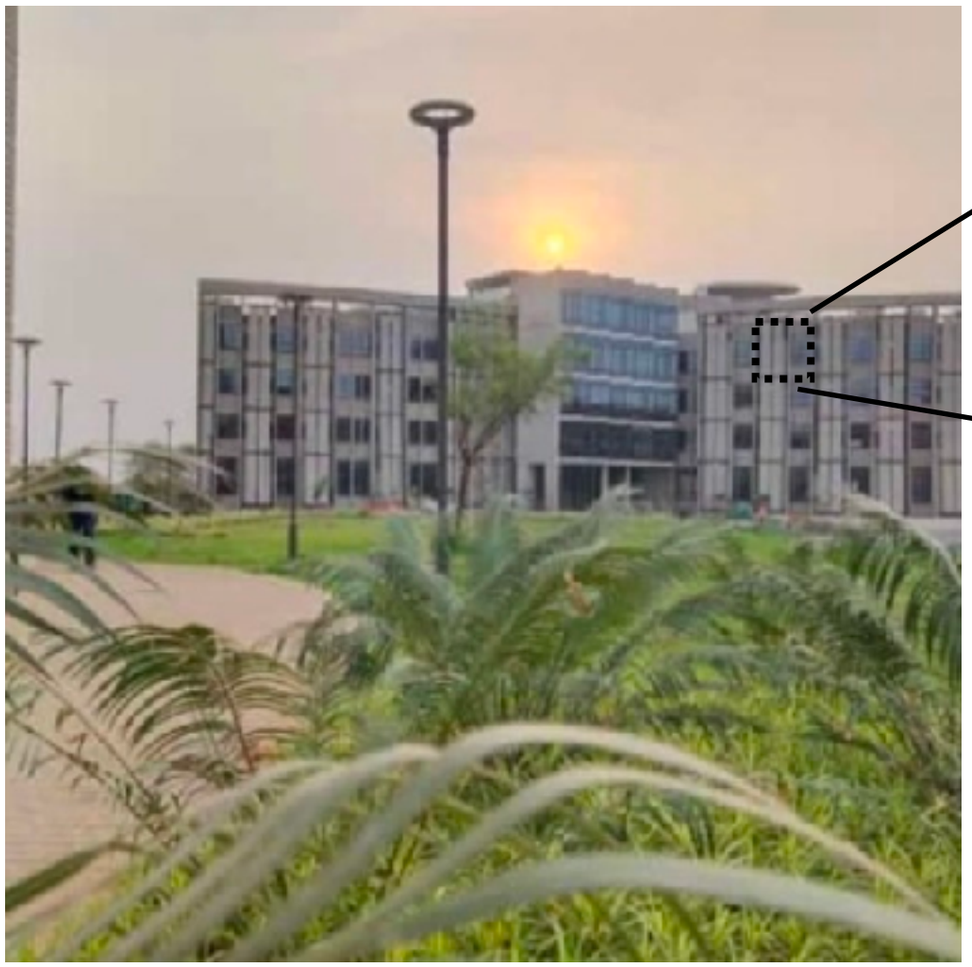
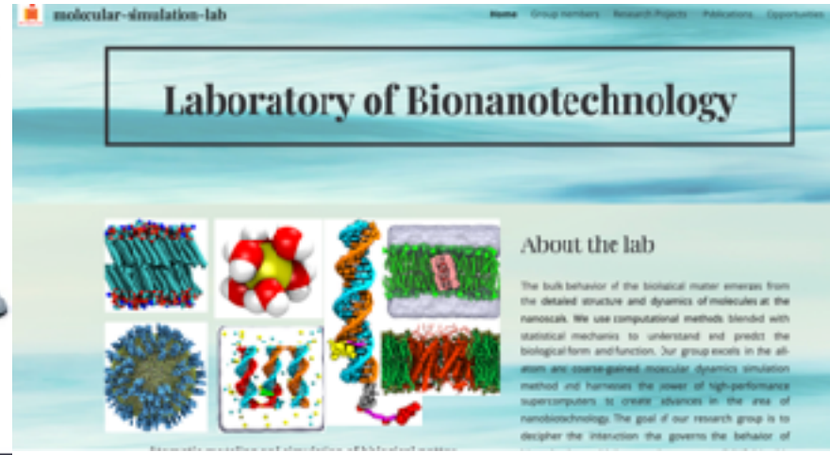
About the instructor

Himanshu Joshi

Laboratory of computational Bionanotechnology

Department of Biotechnology





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About students

- Name and introduction
- Background
- Future Interest
- Contact information

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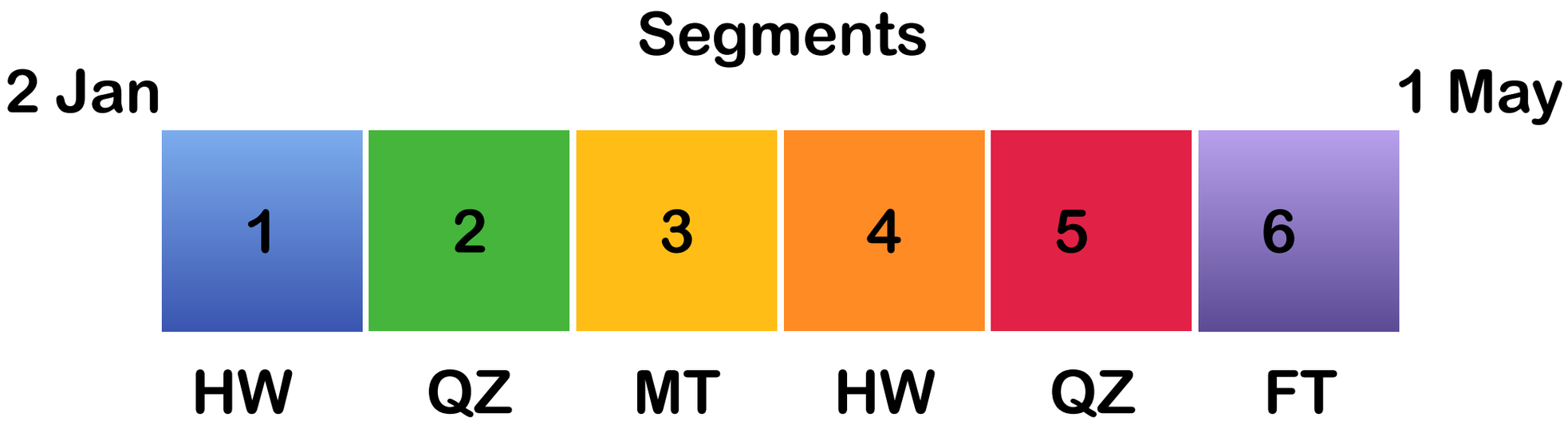
Course contents

- Historical perspective
- Statistical ensembles
- Quantum Mechanics (QM)
- Foundations of Molecular Mechanics (MM),
- Introduction molecular dynamics simulations
- Equation of motion,
- Force-fields, Scheme of integrations,
- Langevin Dynamics,
- Non-bonded Computations,
- Brownian Dynamics,
- Monte Carlo Techniques,
- Coarse Graining Models

Exam and evaluation



Homeworks/ Assignments/Reading project	10
2 quizzes before and after midterm	10
1 midterm	30
1 final term exam	30
Course project and presentation	20
Total	**100**

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Reference Books

1. Molecular modelling and simulation: An interdisciplinary guide *by* Tamar Schlick

2. Statistical mechanics : theory and molecular simulation *by* Mark Tuckerman

3. Computer Simulations of Liquids *by* M.P. Allen and D. J. Tildesly

4. Understanding molecular: From Algorithms to Applications *by* Daan Frenkel and Berend Smit

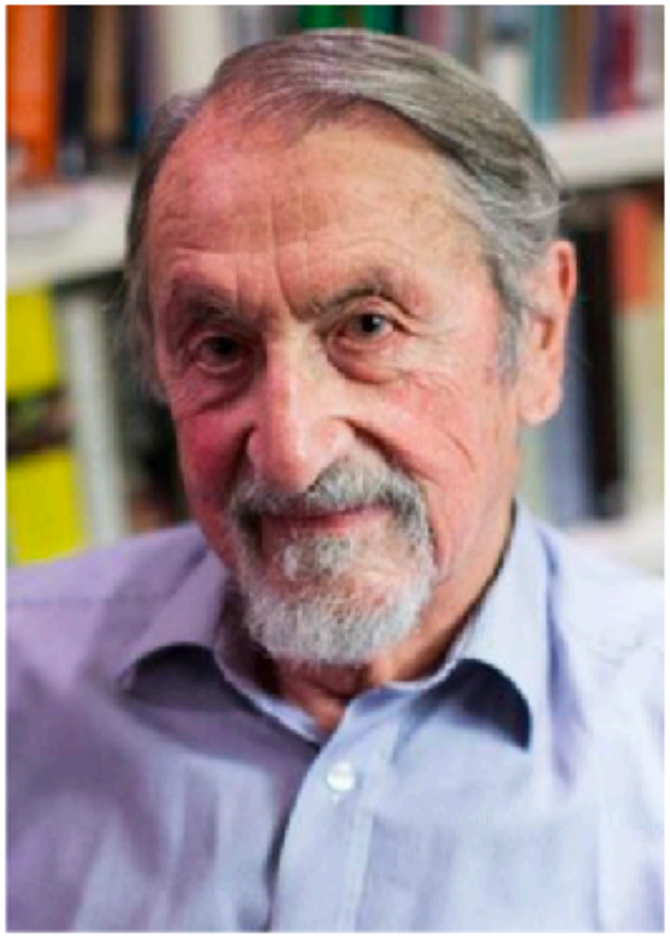
5. Molecular Modelling Principles And Applications by Andrew Leach

6. The art of Molecular dynamics by D. C.Rappaport

Objective of the course

- The course is designed to introduce the idea of biomolecular simulations.
- Using computers to reveal the information and knowledge about the forces that govern the bimolecular assembly and function of biomolecules.
- The students will learn the theory of molecular simulations and are expected to write basic codes to get started with the dynamics of bimolecular simulations.
- Biology by numbers

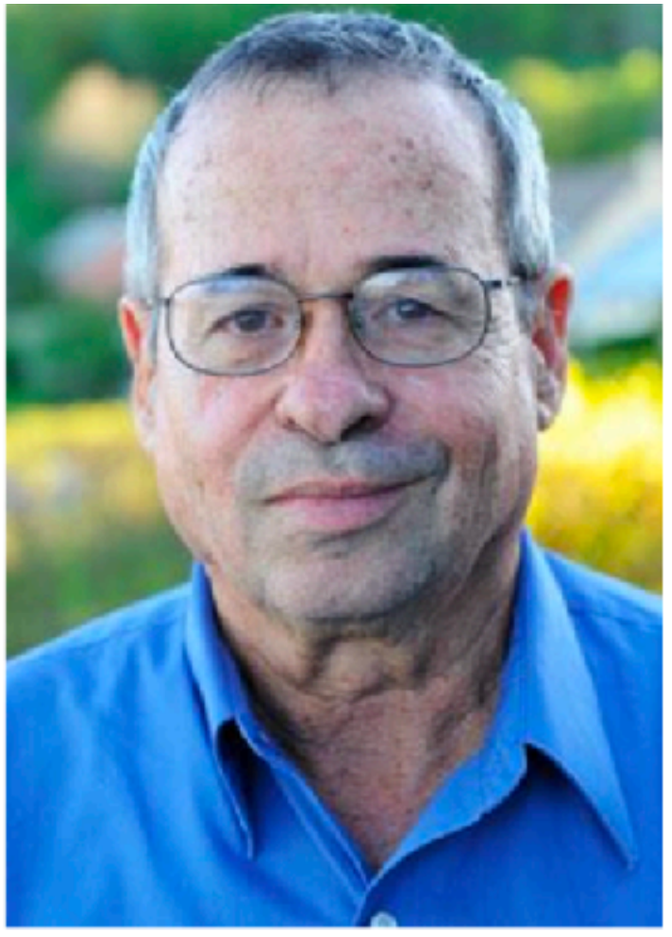
Nobel Prize in Chemistry 2013



M. Karplus
Chemistry
Harvard

Structural

M Levitt,
Bio & Computer Science
Stanford



A Warshel,
Chemistry
USC

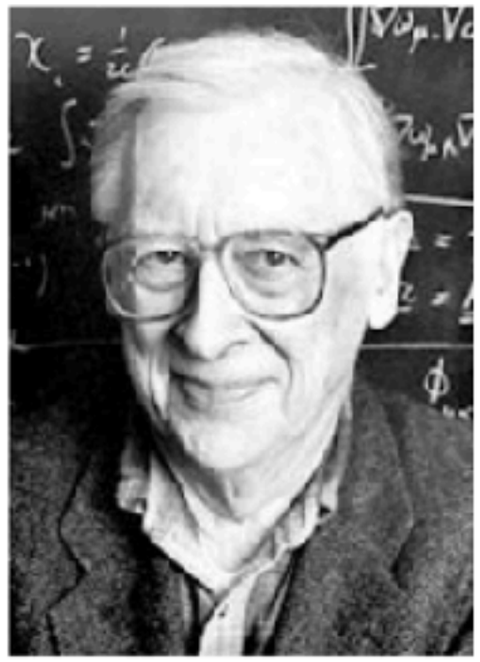
"for the development of multiscale models for complex chemical systems"

Nobel lecture by Martin Karplus

https://www.nobelprize.org/prizes/chemistry/2013/karplus/lecture/

Nobel Prize in Chemistry 1998

Walter Kohn
Physics, University of California, Santa Barbara,



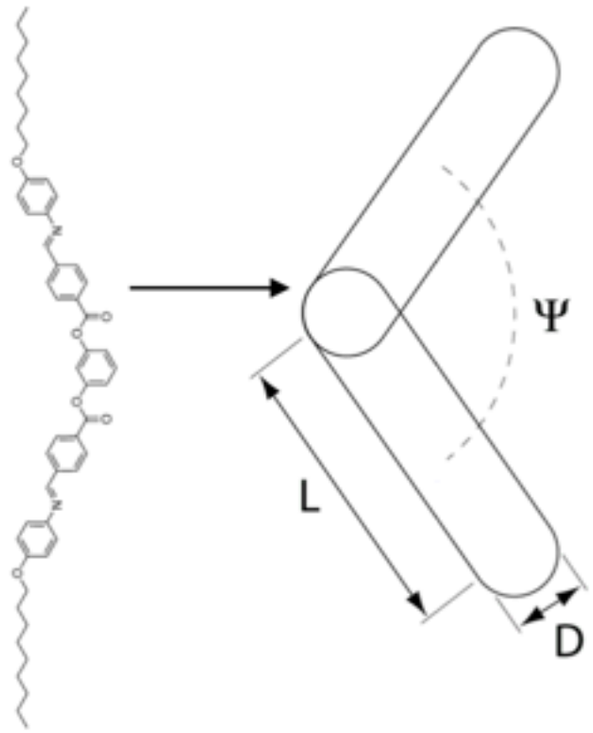
John A. Pople
Chemistry,Northwestern University, Evanston

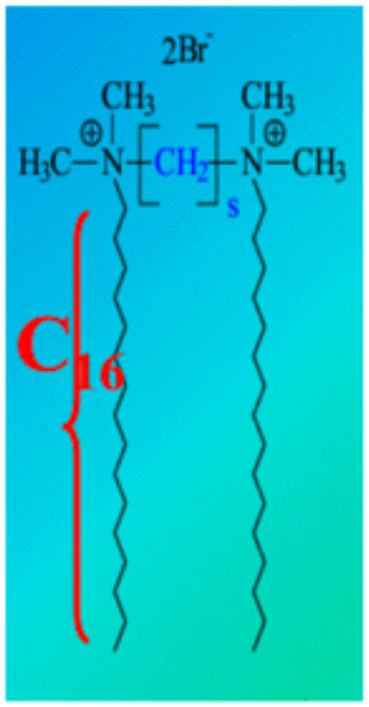
Walter Kohn "for his development of the density-functional theory"and John A. Pople "for his development of computational methods in quantum chemistry".

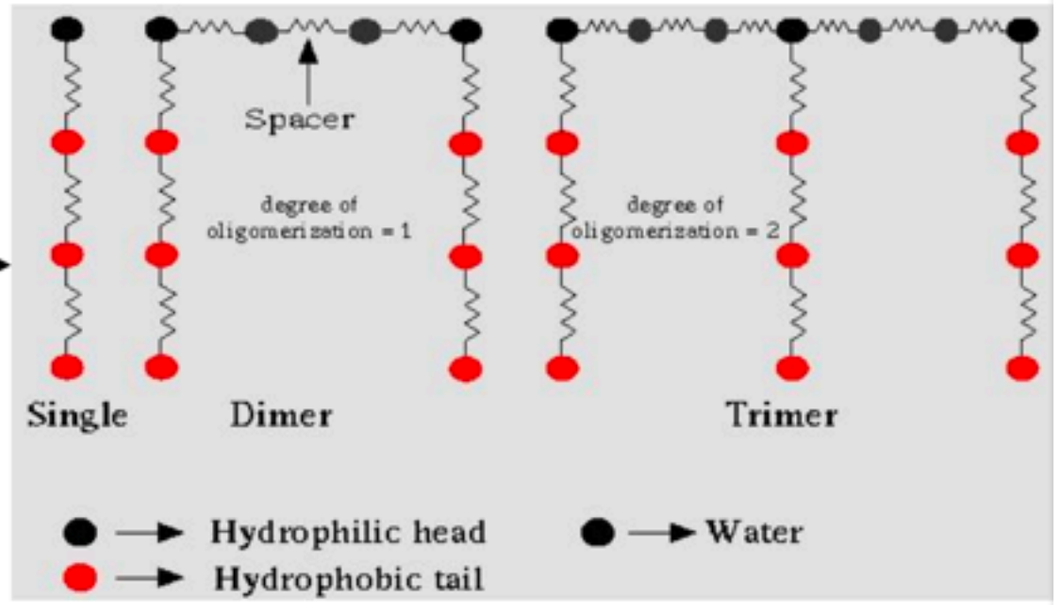
What is molecular simulation

Molecular modeling is the science and art of studying molecular structure and function through model building and computation.

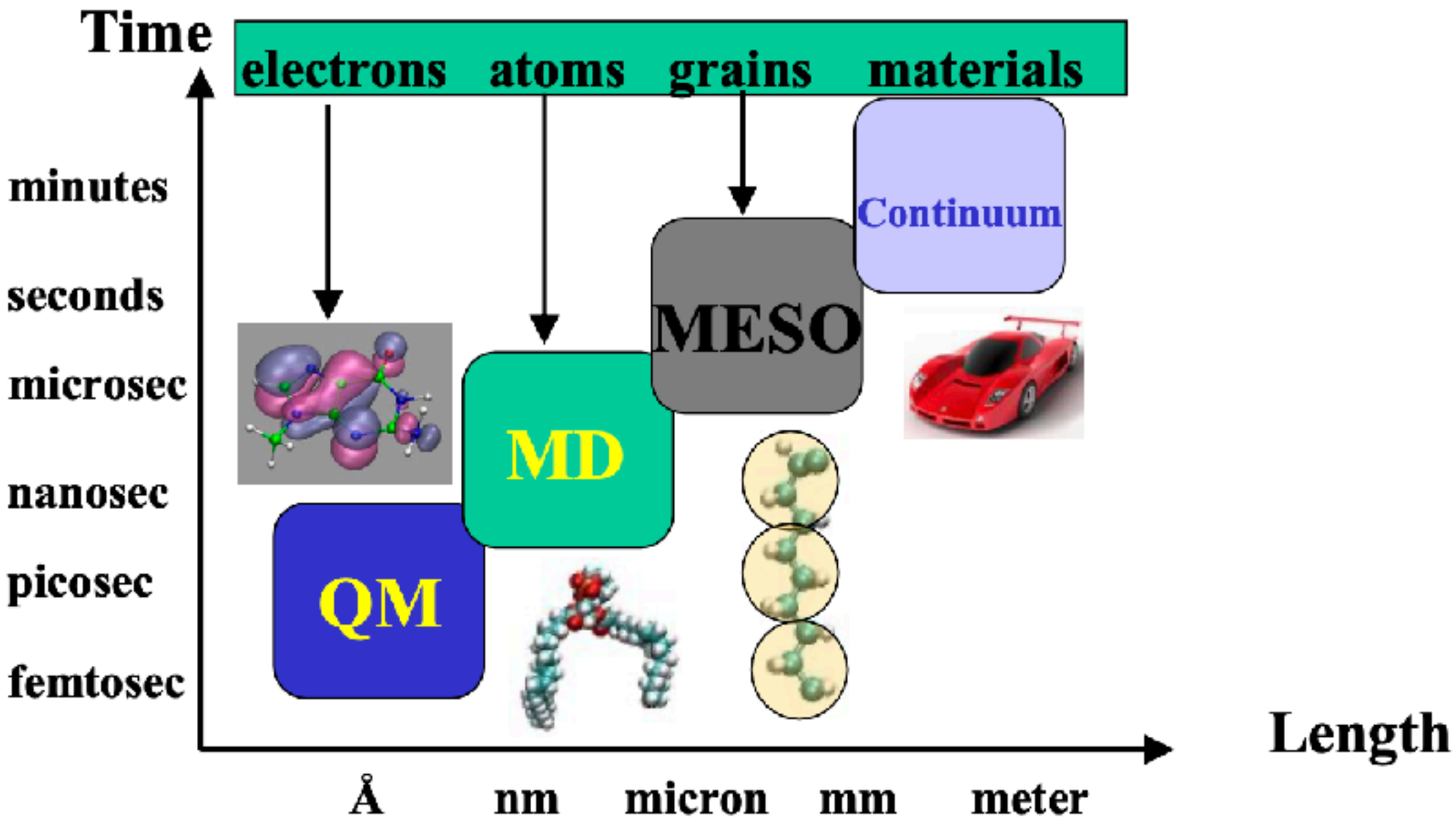
Model building could be as simple as representing molecule by hard/soft sphere (beads) , rigid rods, or other geometrical shape, sphere/beds connected through springs or molecule with full chemical details.







Multi-scale Modeling strategy



High quality multi-scale simulations

- Quantum Mechanical calculation
- First Principles force fields
- Large scale Molecular Dyanmics (MD) simulations
- Mesoscopic modeling (Coarse-grained MD, DPD, BD)
- Macroscopic modeling (finite elements, continuum simulations, Lattice Boltzmann)

Home work and reading material

nature nanotechnology

Letter

https://doi.org/10.1038/s41565-022-01285-z

DNA double helix, a tiny electromotor

Received: 15 March 2022

Accepted: 4 November 2022

Published online: 23 December 2022

Check for updates

Christopher Maffeo[1,2], Lauren Quednau[3], James Wilson[1] & Aleksei Aksimentiev[1,2]

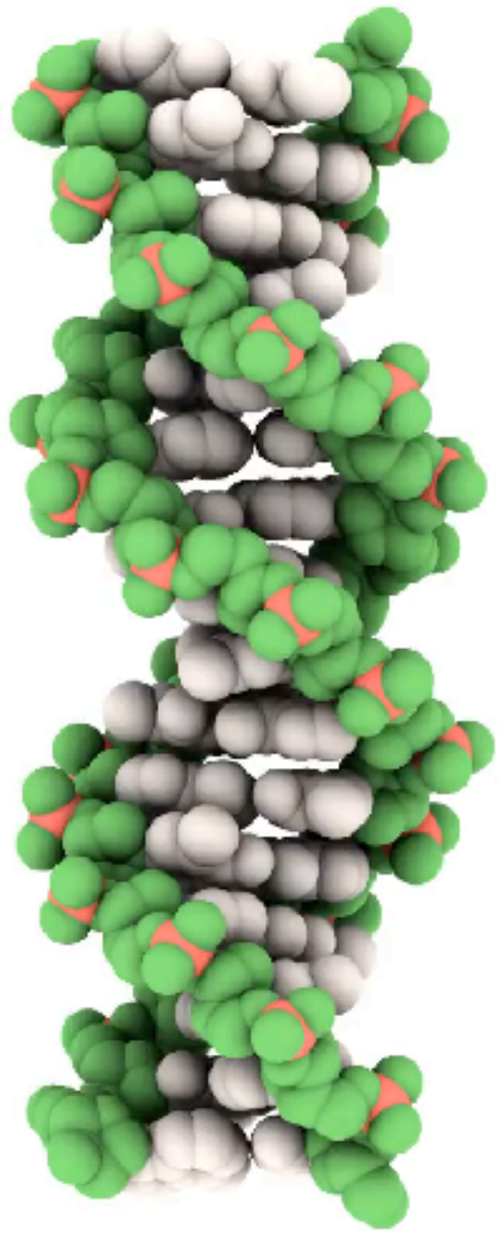
Flowing fluid past chiral objects has been used for centuries to power rotary motion in man-made machines. By contrast, rotary motion in nanoscale biological or chemical systems is produced by biasing Brownian motion through cyclic chemical reactions. Here we show that a chiral biological molecule, a DNA or RNA duplex rotates unidirectionally at billions of revolutions per minute when an electric field is applied along the duplex, with the rotation direction being determined by the chirality of the duplex. The rotation is found to be powered by the drag force of the electro-osmotic flow, realizing the operating principle of a macroscopic turbine at the nanoscale. The resulting torques are sufficient to power rotation of nanoscale beads and rods, offering an engineering principle for constructing nanoscale systems powered by electric field.

Although incremental miniaturization of a man-made machine is possible by simply reducing the size of its parts, radical miniaturization typically requires re-evaluation of the physical principles that govern the machine's operation[1]. For example, in a conventional electromotor, an electric field is transformed into rotary motion by means of electromagnetic induction. However, rotary motion is already best produced at the subnanometre scale using electrostatic actuation[2]. At the nanoscale, biological molecular motors operate with high precision and efficiency[3] using a chemical reaction to bias direction of random displacement[4]. Some molecular motors, such as FoF1 ATP synthase[5] and the bacterial flagellum motor[6], are true electromotors, transforming the energy of a transmembrane electric potential into rotation[7]. Although the biased diffusion mechanism has been realized in purely

concentric DNA origami structures were synthesized to undergo rotary diffusion, driven by stochastic forces[20–23]. Unidirectional rotation of a self-assembled DNA arm was realized by coupling the arm's orientation to the direction of the fluid flow and alternating the flow direction in a cyclic pattern[20]. Yet it has not escaped our notice that the screw shape of a DNA molecule could allow it to function as the simplest possible electromotor.

DNA duplex rotation in electric field

To investigate whether a single DNA duplex will rotate unidirectionally in an external electric field, we constructed an all-atom model of a 16 base pair (bp) DNA duplex submerged in 1 M KCl electrolyte solution (Fig. 1a). Using the all-atom molecular dynamics method, we simulated



https://www.nature.com/articles/s41565-022-01285-z

https://www.nature.com/articles/s41565-022-01288-w

Question of the class

What is chirality and

how does it matter in the structure of DNA molecule ??

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Next Class

4 PM Thursday, 5 January 2023