Statistical mechanics of cellular motion

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Course syllabus

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Course details

Duration: 9×2h lectures + 2h exam
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Course objectives

Beyond its intrinsic beauty and usefulness, the motion of living cells is a puzzle to the physicist. How does a cell harness its internal mess of proteins under strong thermal fluctuations to effect useful work? Do these processes teach us fundamental things about how matter functions out of equilibrium? We will discuss these questions in the context of the cell's cytoskeleton, the most iconic piece of the cell's mechanical machinery. While the nanometer-scale components of this system as well as its large-scale behaviors are each well characterized experimentally, the connection between the two levels is far from understood. This course will discuss this relation through the prism of statistical mechanics, and take the students to some state-of-the-art questions in the field.

Course outline

- **Part 1: The cell's building blocks at equilibrium (*What is the cell made of?*)**
    1. Entropic elasticity of a semiflexible filament: the hydrogen atom of biophysics
    2. From filament to gel: effective medium theory [maybe]
    3. Soft modes, bending and nonaffine elasticity
    4. Solid or liquid? A microscopic view on viscoelasticity [maybe]
- **Part 2: The cell's building blocks out of equilibrium (*Break detailed balance or die.*)**
    1. The brownian ratchet
    2. Molecular motors
    3. Rectifying and amplifying stresses [maybe]
- **Part 3: Hydrodynamic theories of the cell (*From microscopic rules to large-scale flows.*)**
    1. Generalized hydrodynamics
    2. Spontaneous flow in an active gel: a model of cellular motion
    3. Flocking and giant number fluctuations [probably not]

Prerequisites

Required:

- Equilibrium statistical mechanics (canonical & grand canonical ensembles, equipartition...)
  e.g., Chapters 1-3 of Chandler, *Introduction to Modern Statistical Mechanics*

Recommended:

- Fokker-Planck equation
  e.g., Chapter 8 of Van Kampen, *Stochastic Processes in Physics and Chemistry*
- Navier-Stokes equation
  e.g., beginning of Chapter 4 of Guyon, Hulin, Petit, Mitescu, *Physical hydrodynamics*

Useful:

- Linear elasticity theory
  e.g., Chapters 1-2 of Landau & Lifshitz, *Theory of Elasticity*
- Linear response theory including Onsager reciprocity relations
  e.g., Paragraphs 118-120 of Landau & Lifshitz, *Statistical Physics Part 1*
- Derivation of a hydrodynamic theory
  e.g., Chapters 1-8 of Aris, *Vectors, Tensors, and the Basic Equations of Fluid Mechanics*

Recommended reading

Easy reading/watching to get in the mood

This is going to feel a little biological. Don't freak out and embrace the craziness of biological "designs".

- Animated cellular prettiness:
  `https://www.youtube.com/watch?v=B_zD3NxSsD8`
  `https://www.youtube.com/watch?v=uHeTQLNFTgU`
  Same thing with comments: `http://www.youtube.com/watch?v=FzcTgrxMzZk`
- Introductory website with beautiful micrographs:
  `http://cellix.imba.oeaw.ac.at/`

More meaty stuff

Each review article relates to one part of the course.

[1] C P Broedersz and F C MacKintosh. Modeling semiflexible polymer networks. *Rev. Mod. Phys.*, 86:995–1036, July-September 2014.

[2] Frank Jülicher, Armand Ajdari, and Jacques Prost. Modeling molecular motors. *Rev. Mod. Phys.*, 69(4):1269–1281, October 1997.

[3] J Prost, F. Jülicher, and J-F. Joanny. Active gel physics. *Nat. Phys.*, 11(2):111–117, February 2015.