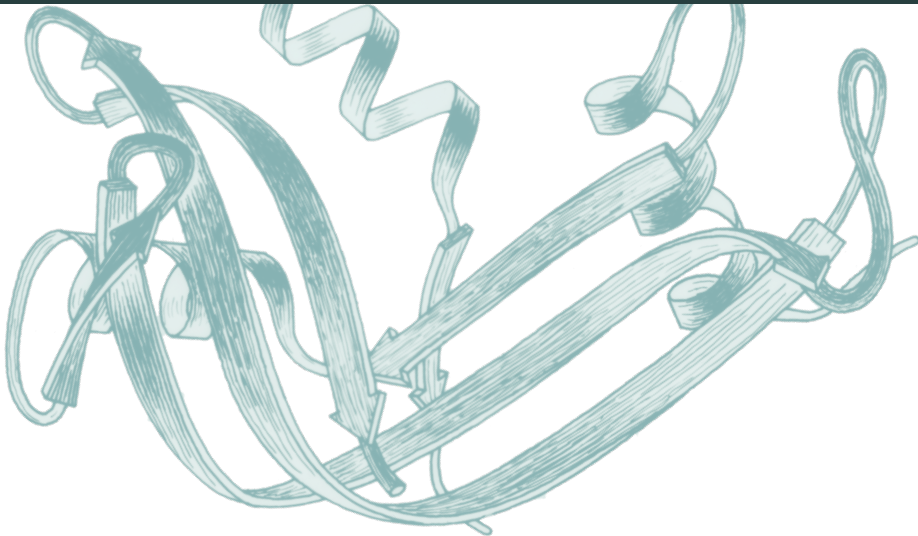


# biophysics

PHYS 320 / 420: Intro to Biological Physics



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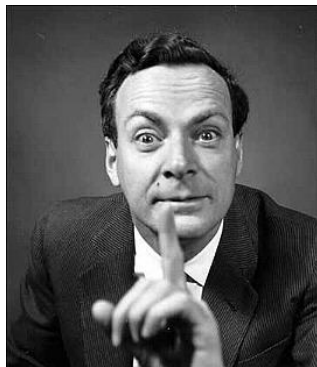
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- ▶ **Problem sets:** 100% of the course grade. Each problem set will be based on a recent paper in the literature, and consist of two parts: an intro explaining why the topic is important and interesting, and then a guided, step-by-step walk through some calculations in the paper (either analytical or numerical). *Working in groups is fine (even encouraged), but please hand in your own write-up.*

# The arrogance of physicists



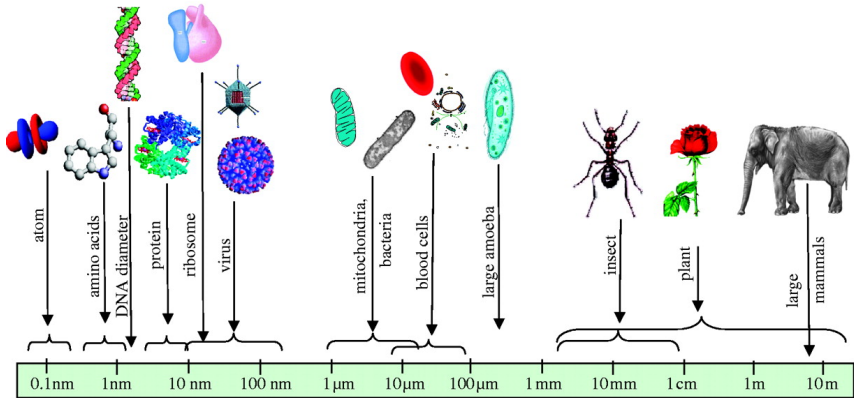
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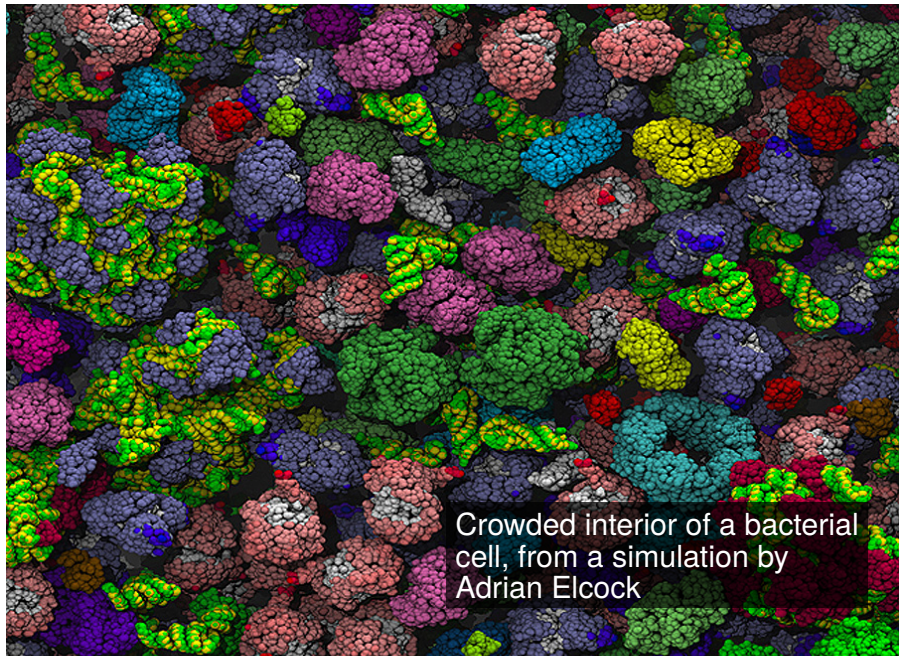
“...everything that living things do can be understood in terms of the **jiggings and wiggings** of atoms.” — Richard Feynman

# Fluctuations rule at scales below 1 $\mu\text{m}$



thermal fluctuations matter

# The not-so-primordial soup



Crowded interior of a bacterial cell, from a simulation by Adrian Elcock

Shaken, not stirred...

See movie in video link on website.

# Virus assembly [Perlmutter *et al.*, eLife (2013)]

See movie in video link on website.

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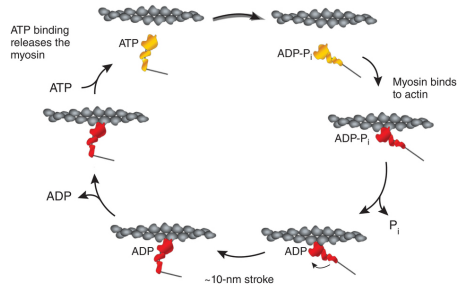
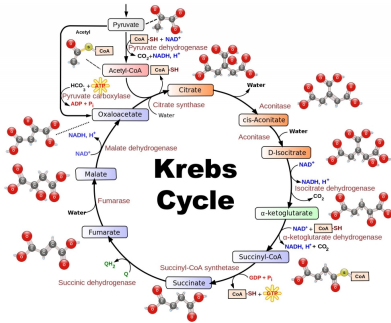
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Biology provides a spectacular guide to the **how** of life. Can physics help provide a non-trivial answer to the **why**?

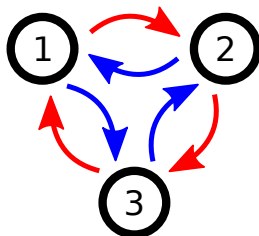
# Finding a mathematical language for biological processes

The bane of every intro bio course: **cycles upon cycles...**



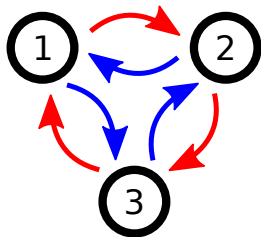
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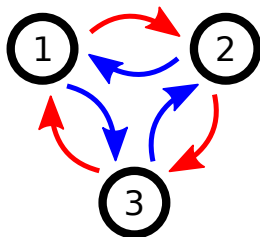
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**Versatility of the approach:** the states can be molecule numbers in a chemical reaction, different structures of a protein, the populations of a genetic variant...

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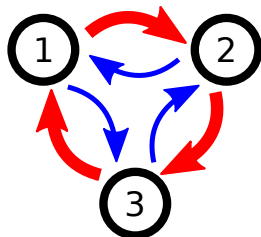
Two broad categories of transition networks:

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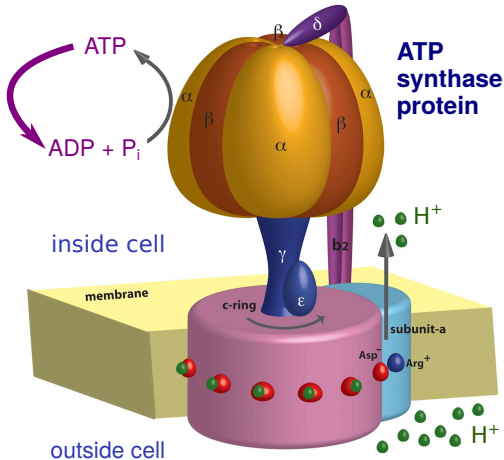
Two broad categories of transition networks:

- ▶ **equilibrium**: any random path on the network and its reverse are equally likely
- ▶ **non-equilibrium**: the symmetry between paths and their reverses is broken  $\Rightarrow$  **requires external fuel source** (we will prove this!)

# Non-equilibrium driving in living systems: ATP

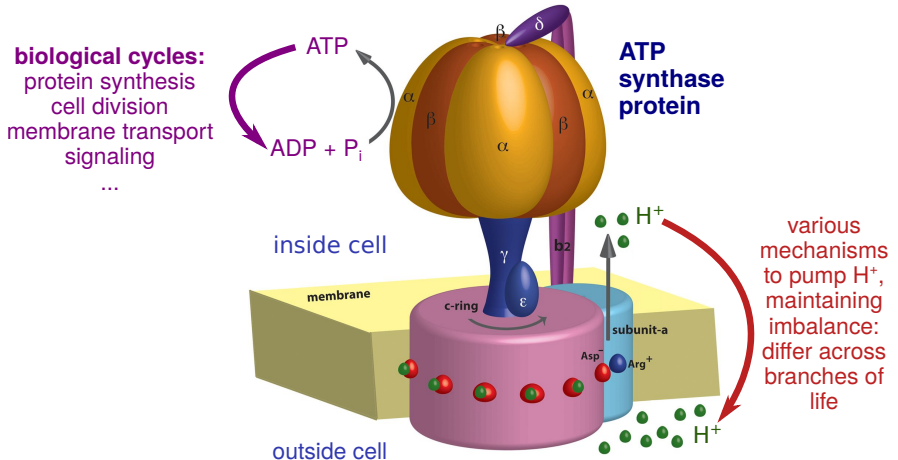
ATP as the prime biological fuel source is as universal as the genetic code.

**biological cycles:**  
protein synthesis  
cell division  
membrane transport  
signaling  
...



# Non-equilibrium driving in living systems: ATP

ATP as the prime biological fuel source is as universal as the genetic code.



Synthesizing ATP is a **nonequilibrium** process, driven by ion imbalances.



# The second law of thermodynamics



SADLY

it does not work

DAMN YOU  
THERMODYNAMICS

Always ruining everything

**Evolutionary conundrum:**  
Self-recharging batteries  
cannot spontaneously  
arise from an equilibrium  
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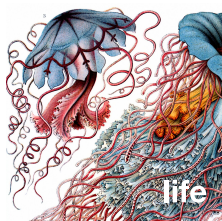
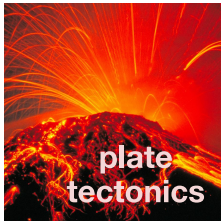
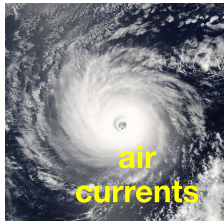
Self-recharging batteries cannot spontaneously arise from an equilibrium primordial soup.

Every persistent imbalance in nature is driven by a more fundamental imbalance:

**If you see a current, search for the power outlet.**

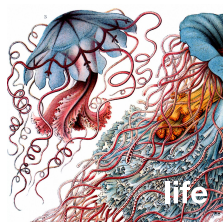
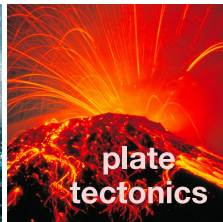
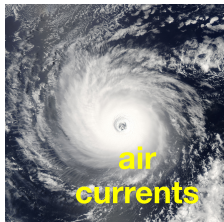
# The fundamental imbalances

All nonequilibrium processes on earth:



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All nonequilibrium processes on earth:



are ultimately “plugged into” two major imbalances:





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**True universality:** The molecular details of potential life-forms on exoplanets will be different, but the constraints of nonequilibrium physics will be the same.

