Introduction to Biophysics
Lecture 1

Careers in Biophysics

History of Biophysics

What is Biophysics?

It is neither “physics for biologists”, nor “physical methods applied to biology”

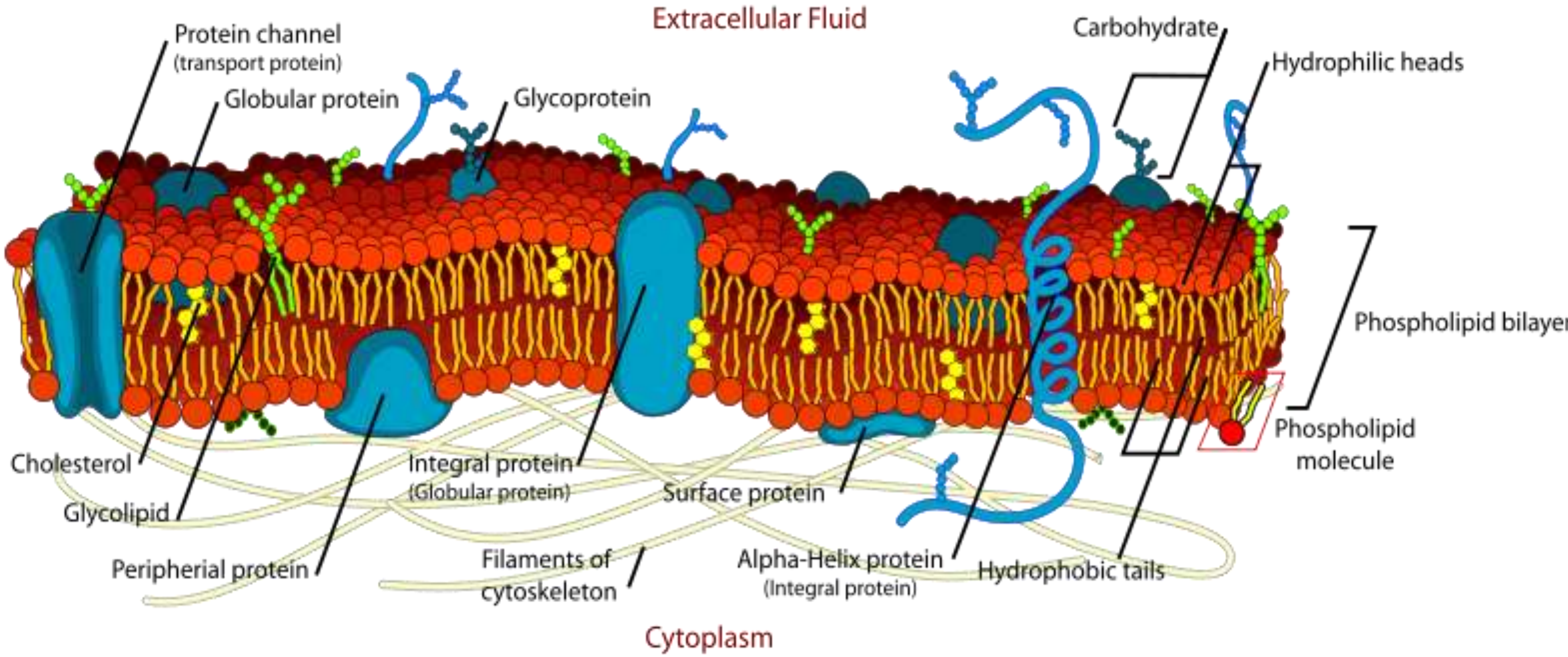
It is a modern, interdisciplinary field of science leading to new approaches for our understanding of biological functions.

Mathematics +Physics +Biology + Chemistry

Paradigm: “Biological system is not simply the sum of its molecular components but is rather their functional integration” –example biological membrane.

Scale from organism to single molecule
Time scales from years to femtoseconds (10^{-15}), 1/1000 ps

Biological Membrane



Highly organized anisotropic structure

Relationship structure–function are central to biophysics

Examples of problems to solve:

How brain processes and stores information?

How the heart pumps blood?

How muscles contract?

How plants use light for grow in photosynthesis?

How genes are switched on and off?

Biophysics discovers how atoms are arranged to work in DNA and proteins.

Protein molecules perform the body’s chemical reactions.

Proteins make the parts of your eyes, ears, nose, and skin that sense your environment.

They turn food into energy and light into vision.

They provide immunity to illness.

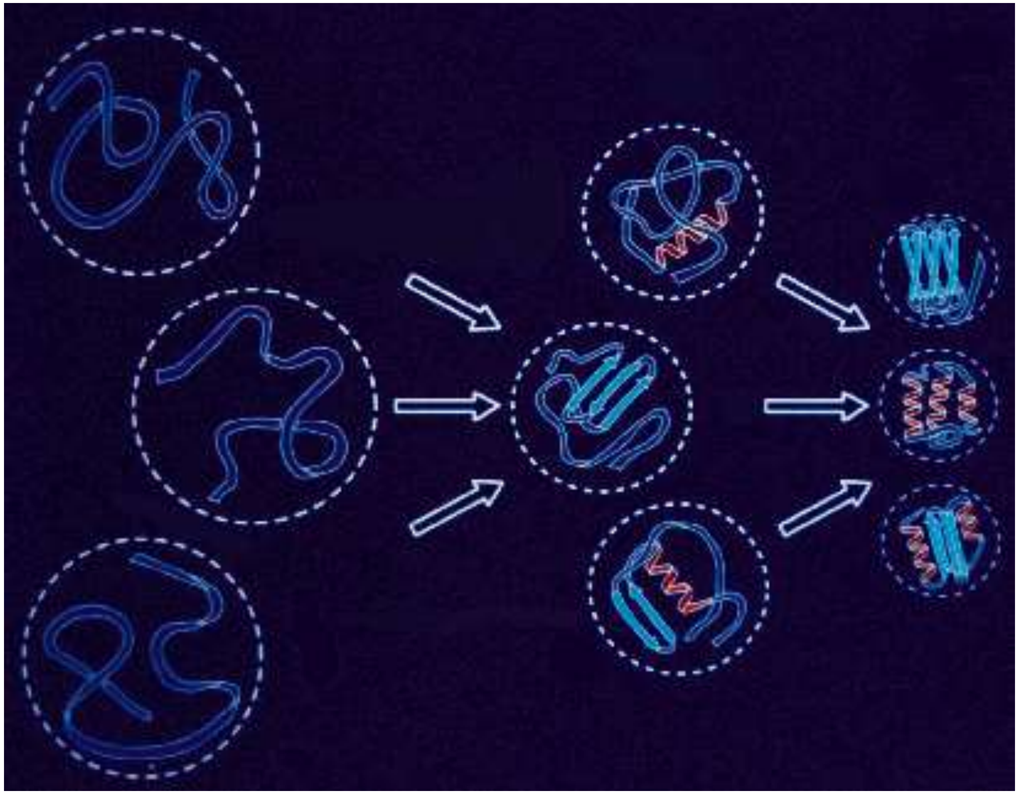
Proteins repair what is broken inside of cells, and regulate growth.

They fire the electrical signals in your brain.

They read the DNA blueprints in your body and copy the DNA for future generations.

Question biophysicists ask:

How do protein Fold?



How three-dimensional structure determines function? Why do molecules and parts of molecules assume the shapes they do? How do they fold into these shapes, and how do they change their structure under changing conditions? The shapes molecules take depend on the physical and chemical forces acting upon them and within them.

X-ray crystallography, nuclear magnetic resonance spectroscopy and scanning probe microscopy, recombinant DNA, computation.

Job Market:

Universities

Industry

Medical Centers

Research Institutes

Government

Impact on biotechnology and medicine

Divisions of Biophysics:

Molecular biophysics

Biomechanics

Membrane Biophysics

Bio-electrochemistry

Environmental Biophysics

Theoretical Biophysics

First Biophysicists

Heraclitus 5th century B.C. – earliest mechanistic theories of life processes, insight into dynamic.

“Change is central to Universe”.

“Logos is the fundamental order of all “on Nature” changes of objects with the flow of time”

“You can not step twice into the same river”

First Biophysicists

Epicurus 3rd century B.C. – atom. Living organisms follow the same laws as non-living objects.

Galen 2th century AD – physician, most accomplished medical researcher of the Roman period. His theories dominated Western medicine for over millennium.

Better anatomy only by Vesalius in 1543

Better understanding of blood and heart in 1628

Leonardo da Vinci 16th century – mechanical principles of bird flight (to use for engineering design) - bionics

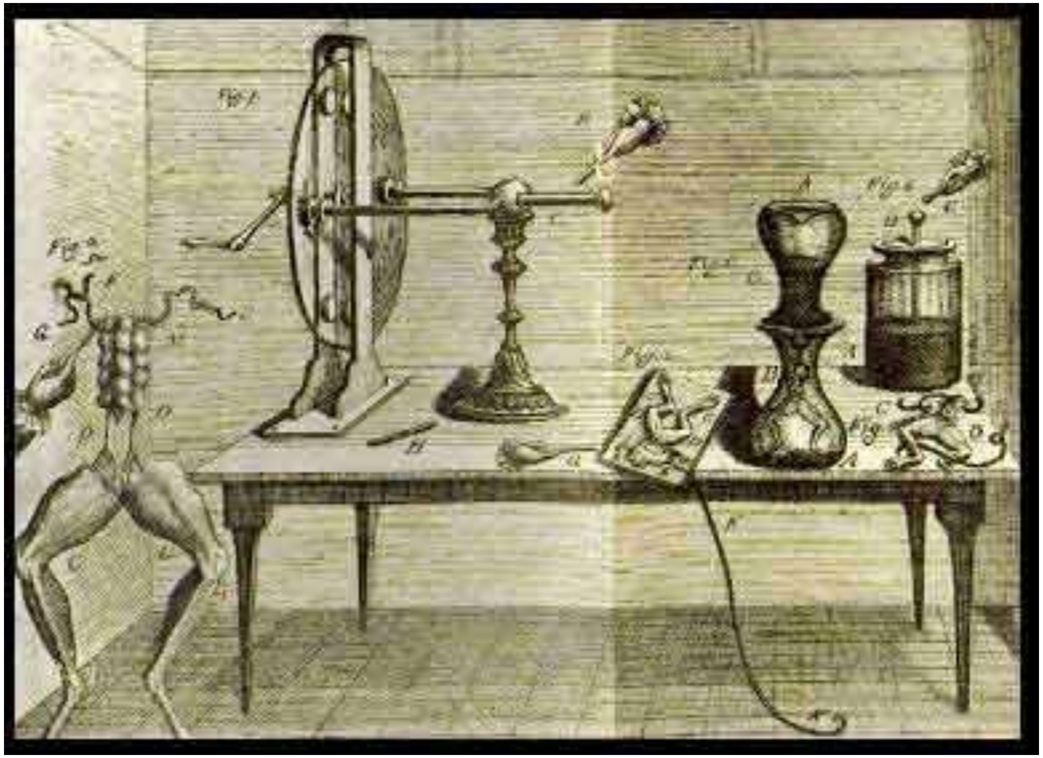
Borelli farther of biomechanics

Giovanni Alfonso Borelli 17th century- related animals to machines and utilized mathematics to prove his theories.

De Motu Animalium – comprehensive biomechanical description of limb’s mobility, bird’s flight, swimming movement, heart function.

Luigi Galvani / Alessandro Volta
Bio-electrochemistry

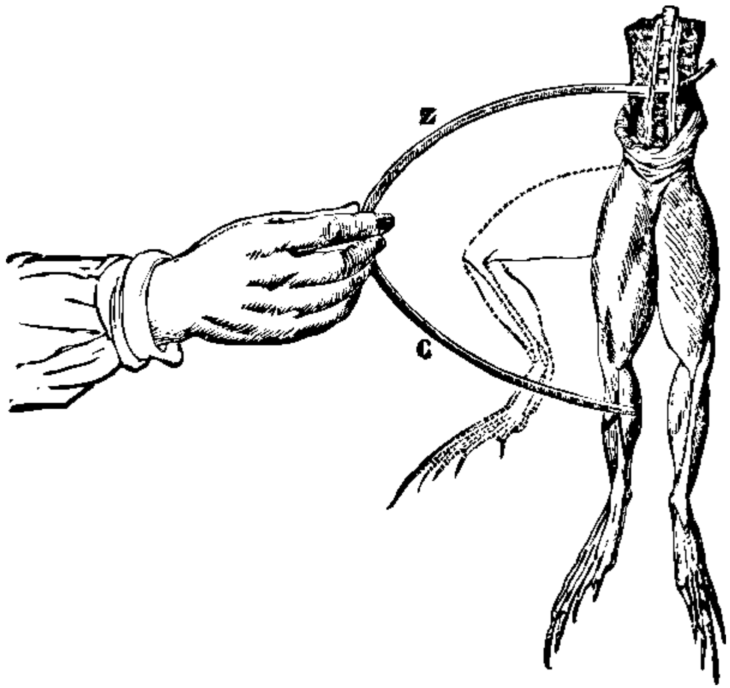
18th (1771) Galvani touched frog nerve with charged scalpel.



Signal transduction in neurons and communication between neurons and muscle has electrical nature.

Luigi Galvani / Alessandro Volta

From frog leg to first battery.



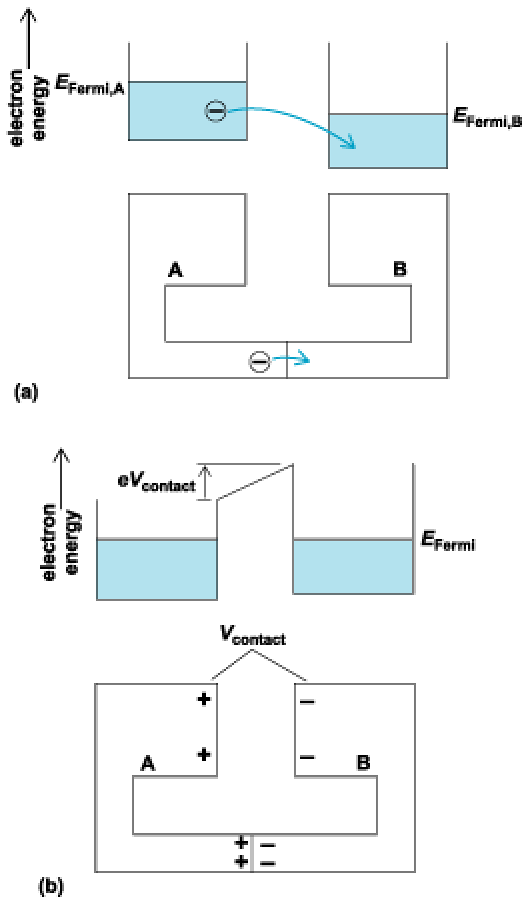
With two different metals effect is stronger.

Contact potential !!

Electric circuit = two different metals + sciatic nerve of the frog
Nerve of the frog's leg = electrolyte and sensor
Metals = electrodes
If close the circuit dead leg will twitch.

Volta created first battery by substituting frog leg with electrolyte.

Development of a contact potential as two conductive materials are brought into thermal equilibrium



(a) Initial charge transfer. (b) Thermal equilibrium. Diagrams show corresponding electron energy distributions.
E_{Fermi} = Fermi level; $V_{contact}$ = contact potential difference

History of discoveries in Biophysics:

First law of thermodynamic

Optical aspects of the human eye

Theory of hearing

Brown’s motion

Osmotic process

Nonequilibrium thermodynamics

Discovery of X-rays – emergence of radiation biophysics

Transmission of order from one organism to it’s descendants

Über die Natur der Genmutation und der Genstruktur.

Von

N. W. Timoféeff-Ressovsky, K. G. Zimmer und M. Delbrück.

Vorgelegt von A. Kühn in der Sitzung am 12. April 1935.

The major advance in understanding the nature of gene mutation and gene structure. The work was a keystone in the formation of molecular genetics.

WHAT IS LIFE?

The Physical Aspect of the Living Cell

BY

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History of discoveries in Biophysics:

Discovery of DNA structure

Information theory

Statistical physics of biopolymers

Thermodynamics Review

1. Formalism to keep track (accounting) of energies

2. Predict if a process is spontaneous or not

3. How much useful energy can be obtained from a chemical rxn as it proceeds from:

$$\boxed{\text{Initial Conditions} \longrightarrow \text{Equilibrium}}$$

Thermodynamics

First Law: **Energy conservation**

Internal energy (E).- Total energy content of a system. It can be changed by exchanging heat or work with the system:

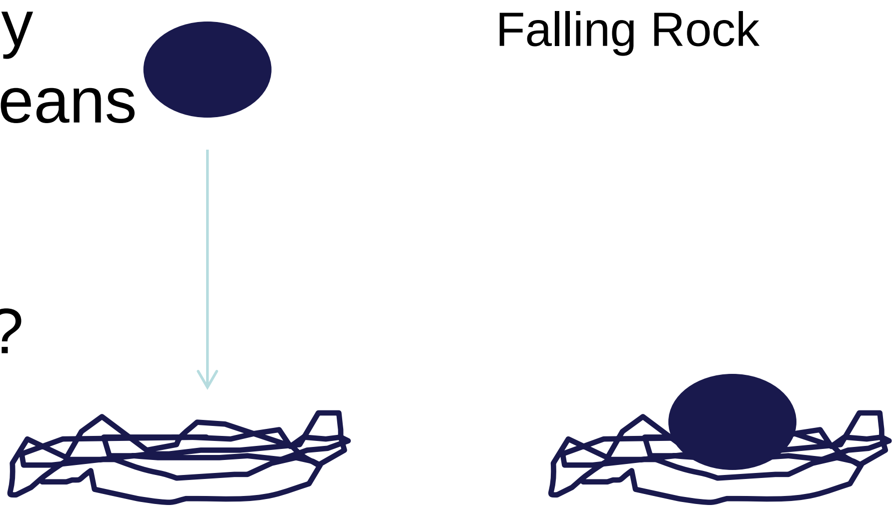
E↑
- Heat-up the system
- Do work on the system

E↓
- Cool-off the system
- Extract work from the system

$$\Delta E = q + w$$

In the falling rock its kinetic energy is transformed into heat (which means into kinetic energy of molecules).

Can rock spontaneously jump up?



Newton laws and the first law of thermodynamics do not prohibit the backward process: the molecules of mud kicking the rock up in the air. 2^{nd} law of thermodynamics says that spontaneous processes occur in the direction that increases disorder.

The **second law of thermodynamics** is an expression of the universal principle of increasing entropy, stating that the entropy of an isolated system which is not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium.

Thermodynamics

The macroscopic (thermodynamic) definition of entropy:

$$dS = dq_{rev}/T$$

1854 Rudolf Clausius – introduced entropy as a parameter of phenomenological thermodynamics

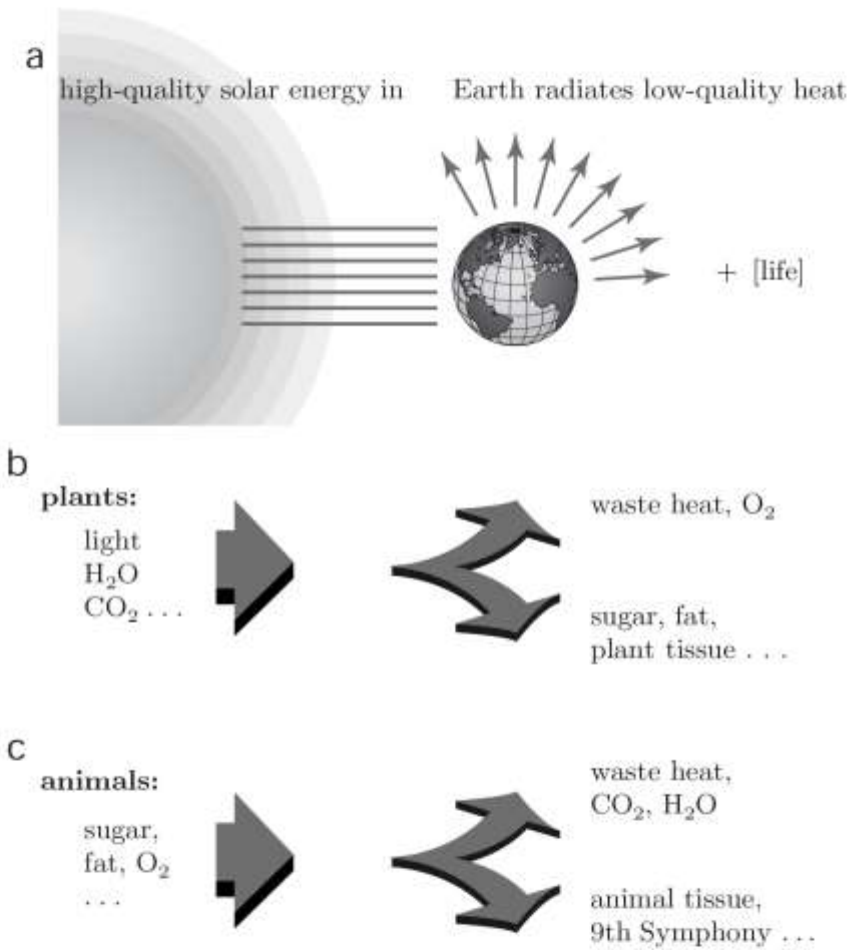
i.e., for a system undergoing a change from an initial state A to a final state B, the change in entropy is calculated using the heat exchanged by the system between these two states when the process is carried out reversibly.

Question biophysicists ask: How life generates order?

2nd law of thermodynamic - in isolated system molecular disorder never decreases spontaneously.

Question: why Earth is full of life which is highly organized?

Vitalism?



The Concept of **Free Energy**:

-“useful” energy of a system
- the part of total energy that can be harnessed to do “useful” work

$$F=E-TS$$

(total energy – randomness (or disorder))

If $\Delta F<0$ – process is spontaneous, T=constant

F can decrease if

E decreases (exmp. - heat loss)
S increases (disorder tents to increase)

Life doesn’t create order from nowhere. Life captures order, ultimately from the Sun. Prosesses of free energy transduction then transmit order through the biosphere.

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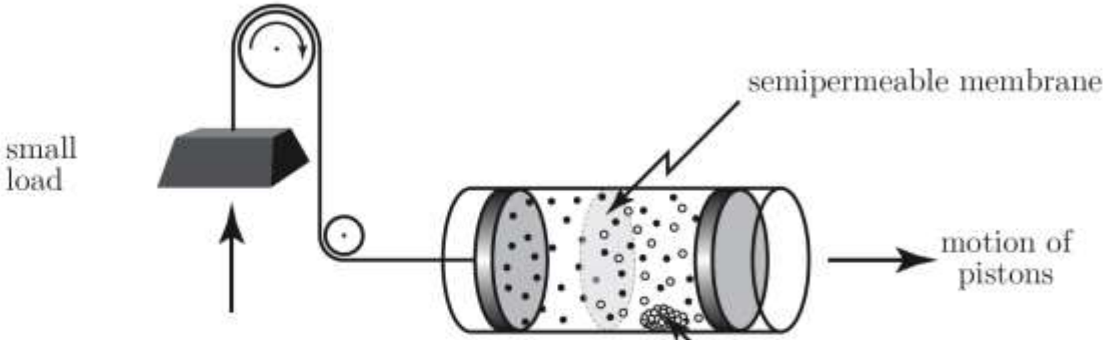

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