LECTURE 1

BB 101

MODULE: *PHYSICAL BIOLOGY*

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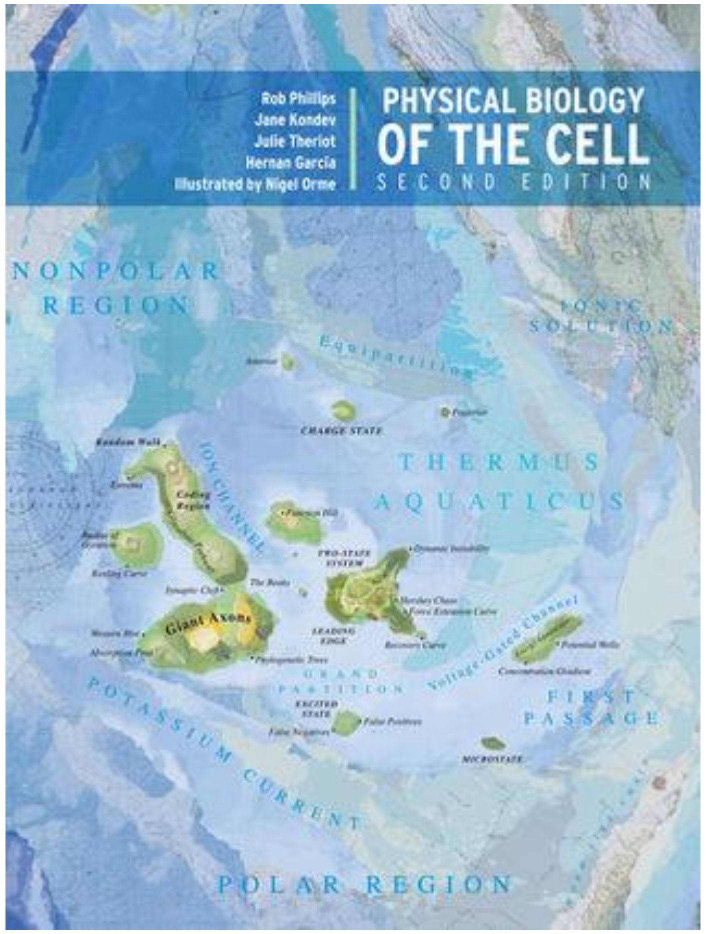
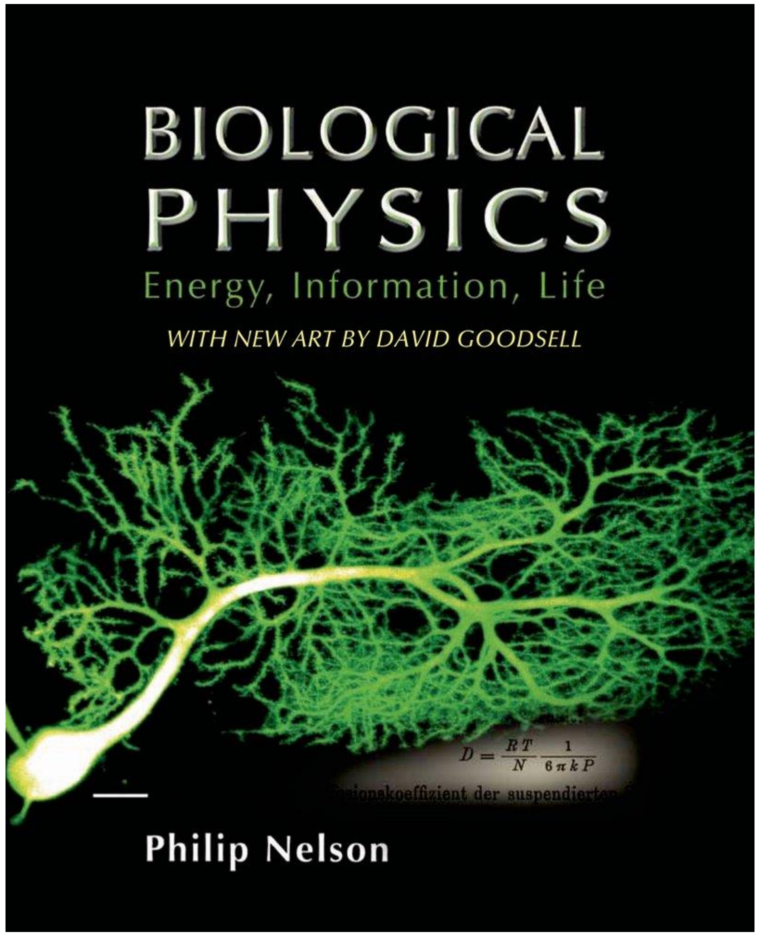
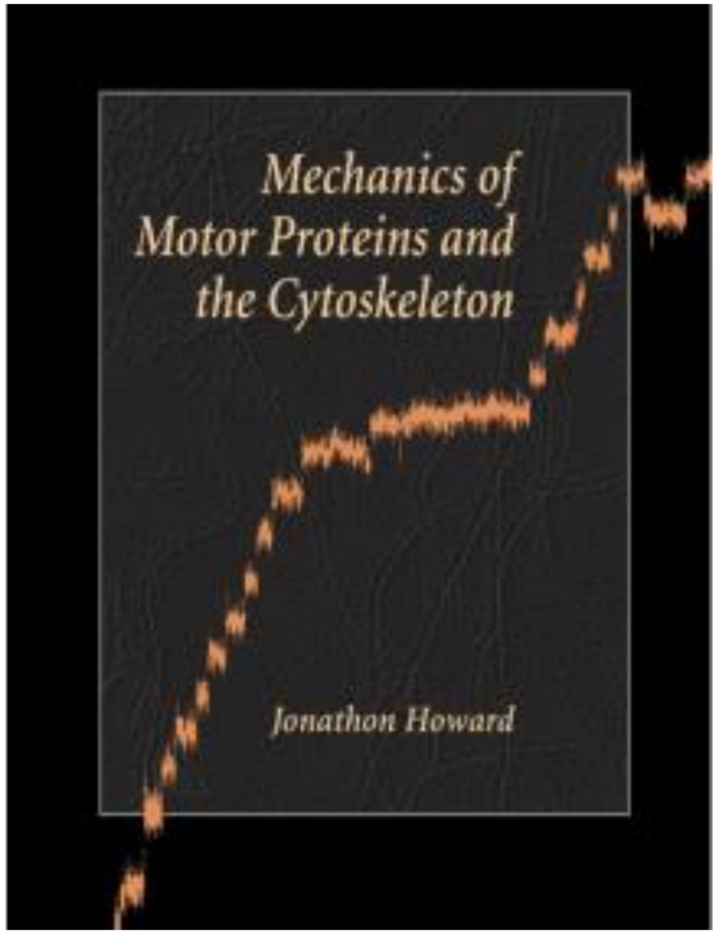
Reference Books

Some of the lecture material can be found in one of the following three book







1. Physical Biology of the cell, R. Phillips, J. Kondev, J. Theriot, H. Garcia (Publisher: Garland Science)
2. Biological Physics, Philip Nelson (Publisher: W. H. Freeman)
3. Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard (Publisher: Sinauer Associates Inc.)

A topic guide for each lecture will be provided along with lecture slides

PHYSICAL BIOLOGY LECTURES and TUTORIALS

Lecture No.	Date	Day	Batch			Time
1	24-01-22	MON	D4			02:00 AM-03:30 PM
1	25-01-22	TUE		D2		03:30 PM-05:00 PM
2	27-01-22	THU	D4			02:00 AM-03:30 PM
2	28-01-22	FRI		D2		03:30 PM-05:00 PM
3	31-01-22	MON	D4			02:00 AM-03:30 PM
3	01-02-22	TUE		D2		03:30 PM-05:00 PM
4	03-02-22	THU	D4			02:00 AM-03:30 PM
4	04-02-22	FRI		D2		03:30 PM-05:00 PM
5	07-02-22	MON	D4			02:00 AM-03:30 PM
5	08-02-22	TUE		D2		03:30 PM-05:00 PM
6	10-02-22	THU	D4			02:00 AM-03:30 PM
6	11-02-22	FRI		D2		03:30 PM-05:00 PM

Tutorial No.	Date	Day	Batch		Time
1	02-02-2022	WED	D2	D4	08:30 AM-09:30 AM
2	09-02-2022	WED	D2	D4	08:30 AM-09:30 AM
3	16-02-2022	WED	D2	D4	08:30 AM-09:30 AM

Teaching Assistants

Tutorial Room	TA1	TA2	Backup TA
1	**Dhir Priyam Singh**	**Joel Abraham**	**Khyati Jain**
2	**Gupta Ayushi Sanjay**	**Vishalkumar Keshavbhai Savaliya**	
3	**Meghna Dixit**	**Jatin Nareshbhai Jagani**	
4	**Aryan Khanna**	**Anirudh Jairam**	
5	**Dhruv Patwa**	**Nayan Jyoti Das**	
6	**Vipin Rajeshkumar Ochiramani**	**Singh Ankit Brijpal**	
7	**Ali Asgar Saifee**	**Karishma Ghosh**	
8	**Prajwal Chunilal Patil**	**Ishika Gupta**	
9	**Gaurish Manoj Loya**	**Rajiv Kumar**	
10	**Nitish Agrawal**	**Tanya Kaur**	**Susweta Das**
11	**Vishal Srivastava**	**Prachi Ashok Wankhade**	
12	**Gautam Tanwar**	**Simhadri Aditya**	
13	**Shah Heetak Jayesh**	**Chinmay Vilas Mhatre**	
14	**Vaishnavi Gaurav Agarwal**	**Meenam Pokhrel**	
15	**Khushi Sagar Gosalia**	**Priyanka Ashok Shedbale**	
16	**Akshat Koolwal**	**Sankar M**	
17	**Ritwik Sudesh Kadu**	**Dwiteeya Chaudhury**	
18	**Aastha Kapoor**	**Stuti Gupta**	**Pawan Kumar**
Hindi	Jyotirmoy Roy		

COURSE OVERVIEW

Module	Faculty	Quiz	Mid-sem	End-sem	Total
Molecular & Cell Biology (MCB)	Prof. Sanjeeva Srivastava	5	20	0	25
Molecular & Cell Biology (MCB)	Prof. **Sreelaja Nair**	-	25	0	25
Physical Biology	Prof. Ambarish Kunwar	5	0	20	25
Biomedical Engineering	Prof. **Hari Varma**	5	0	20	25

What is Physical Biology or Biophysics?

Bridge between Physics and Biology

- Biology is the study of life in its variety and complexity
- Biological studies range from level of biomolecules, cells, organisms to level of ecosystems

- On the other hand, physics looks for mathematical laws of nature
- Make detailed predictions about phenomenon that drive the systems

Physical Biology or Biophysics

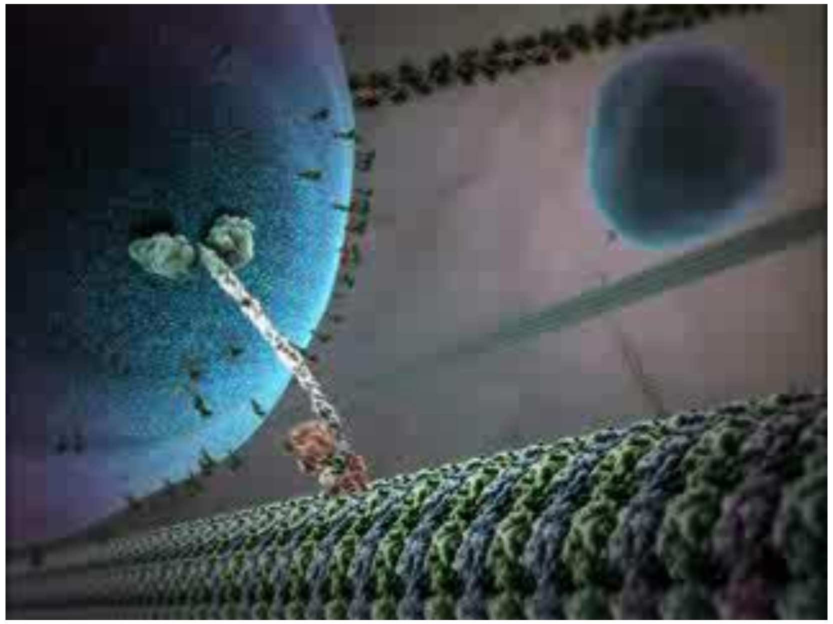
Look at some of the biological systems and phenomena at microscopic scale and understand them by using our knowledge physical laws and principles to gain important insights into these systems and phenomena

Why our cells use motor proteins for transportation?

- Motor proteins are millions of times smaller macroscopic motors

- They work on the same principles as macroscopic motors i.e.they use energy to do work.

Can we design artificial motor proteins by a simple scaling of size?



How do these biological nano-machines work?

Insights gained may help you to design artificial nano-machines

Video Source:http://multimedia.mcb.harvard.edu/
Figure Source: http://www.wpclipart.com/working/vehicles/dump_truck/dump_truck_green.png.html

Figure Source: http://edition.cnn.com/2016/10/05/world/nobel-prize-2016-chemistry-molecular-machines/index.html

for the design and synthesis of molecular machines

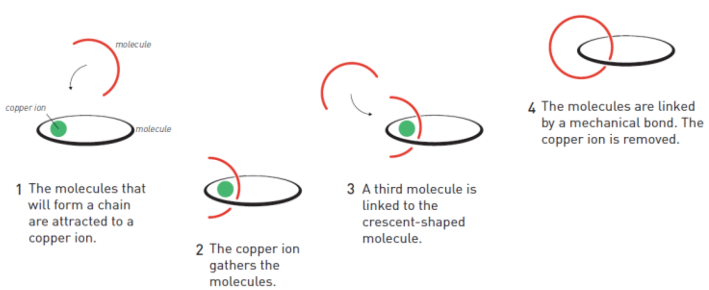


Figure 1. Jean-Pierre Sauvage used a copper ion to interlock molecules using a mechanical bond.

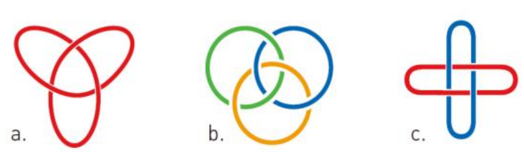


Figure 2a. Jean-Pierre Sauvage has created a molecular trefoil knot. This symbol is found in Celtic crosses, runestones, depictions of Thor's hammer (Mjölnir) and, in Christianity, it symbolises the Holy Trinity. **b.** Fraser Stoddart has produced molecular Borromean rings. The Italian Borromeo family used the symbol on their shield. It is also found on Old Norse picture stones and has symbolised the Holy Trinity. **c.** Stoddart and Sauvage have made a molecular version of Solomon's knot, a symbol of King Solomon's wisdom. It has been frequently used in Islam and is found in Roman mosaics.

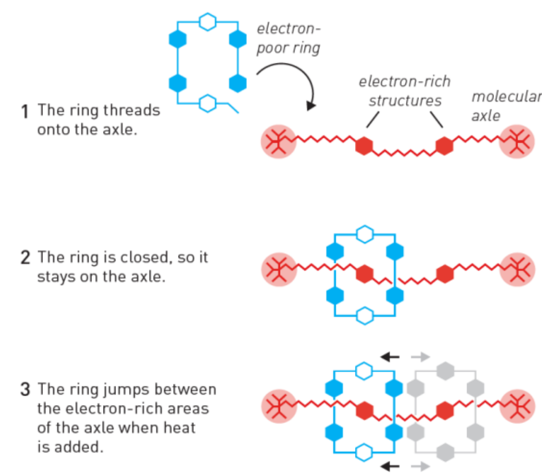


Figure 3. Fraser Stoddart created a molecular shuttle that could move along an axle in a controlled manner.

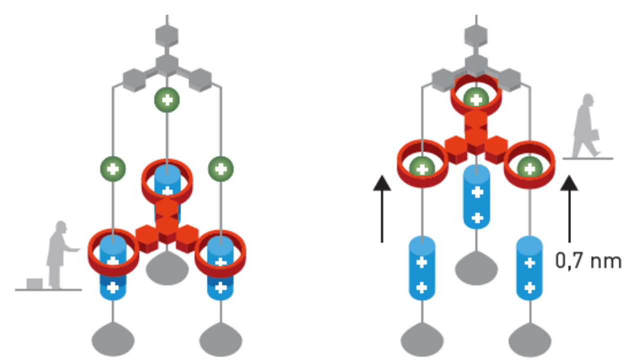


Figure 4. Fraser Stoddart's molecular lift.

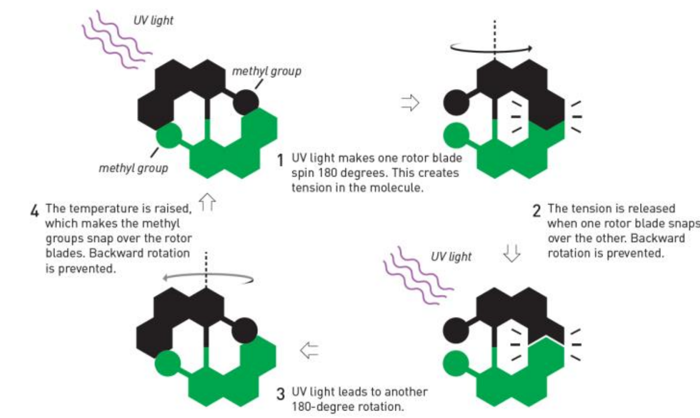


Figure 6. When Ben Feringa created the first molecular motor, it was was mechanically constructed to spin in a particular direction. His research group has optimised the motor so that it now spins at 12 million revs per second.

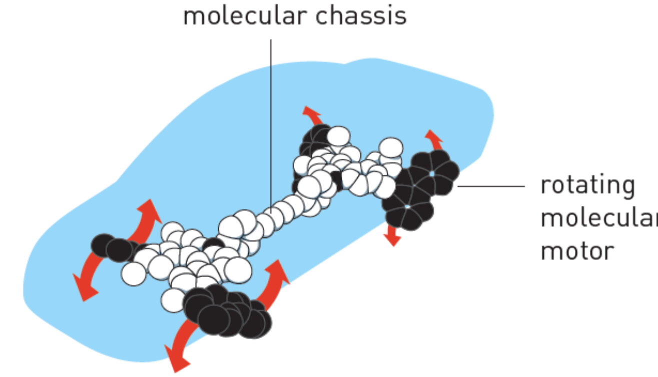
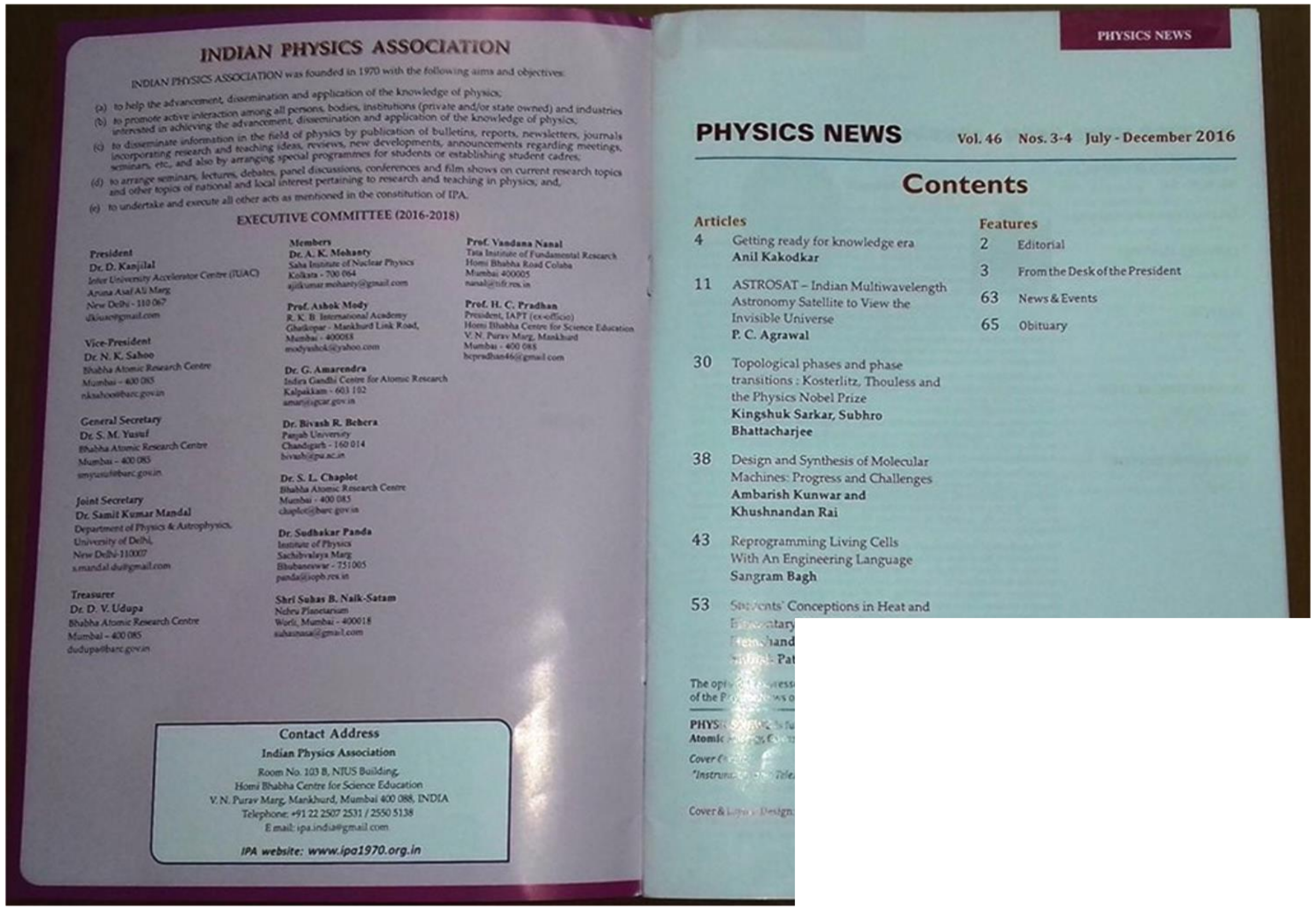


Figure 7. Ben Feringa's four-wheel drive nanocar.

Figure Source: https://www.nobelprize.org/nobel_prizes/chemistry/laureates/2016/popular-chemistryprize2016.pdf



INDIAN PHYSICS ASSOCIATION

INDIAN PHYSICS ASSOCIATION was founded in 1970 with the following aims and objectives:

(a) to help the advancement, dissemination and application of the knowledge of physics;
(b) to promote active interaction among all persons, bodies, institutions (private and/or state owned) and industries interested in achieving the advancement, dissemination and application of the knowledge of physics;
(c) to disseminate information in the field of physics by publication of bulletins, reports, newsletters, journals incorporating research and teaching ideas, reviews, new developments, announcements regarding meetings, seminars, etc., and also by arranging special programmes for students or establishing student cadres;
(d) to arrange seminars, lectures, debates, panel discussions, conferences and film shows on current research topics and other topics of national and local interest pertaining to research and teaching in physics; and,
(e) to undertake and execute all other acts as mentioned in the constitution of IPA.

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PHYSICS NEWS Vol. 46 Nos. 3-4 July - December 2016

Contents

Design and Synthesis of Molecular Machines: Progress and Challenges

Ambarish Kunwar and Khushnandan Rai

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The Nobel Prize in Chemistry 2016 was awarded jointly to Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard (Ben) L. Feringa for the design and synthesis of molecular machines. They have developed molecules and machines with controllable movements which can perform work when energy is supplied to them. We hope that these tiny molecular machines will most likely revolutionize the development of various new materials and technologies in the twenty first century, in a manner similar to the Industrial Revolution in the nineteenth century brought about by their macroscopic counterparts such as steam and internal combustion engines. This article summarizes the groundbreaking work done by them, as well as some challenges ahead from a physicist's perspective, and how they can be handled.

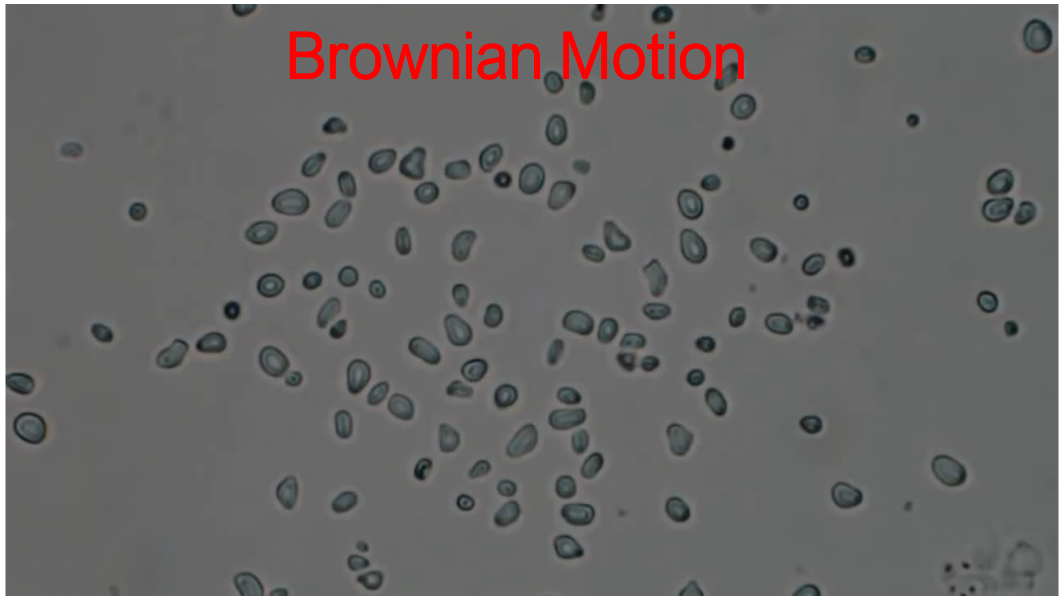
How swimming of a bacteria is different from swimming of a fish/human?

What type of forces play dominant role for microscopic and macroscopic swimmers?

Insights gained may help you to design artificial micro-swimmers

Video Source:https://www.youtube.com/watch?v=a_5FToP_mMY
Video Source: https://www.youtube.com/watch?v=wnzlPwaf7cs
Video Source: https://www.youtube.com/watch?v=iaMpz8Bqi_s

Thermal Energy and its importance



Video Source: https://www.youtube.com/watch?v=R5t-oA796to

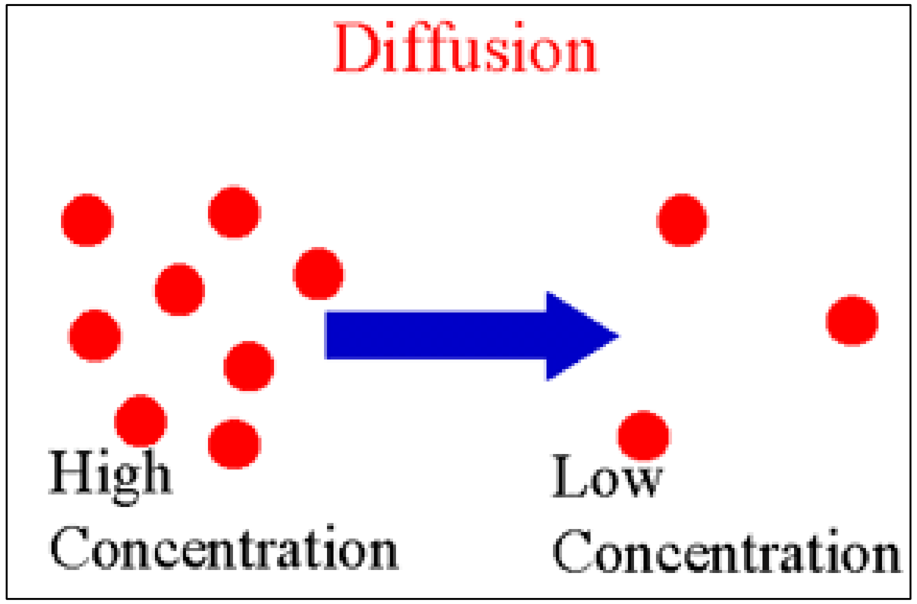


Figure Source: http://www.occc.edu/biologylabs/Documents/Cells%20Membranes/Diffusion_Definition.htm

Figure Source: http://blog.colloidsforlife.com/wp-content/uploads/2011/10/Milk-216x300.jpg

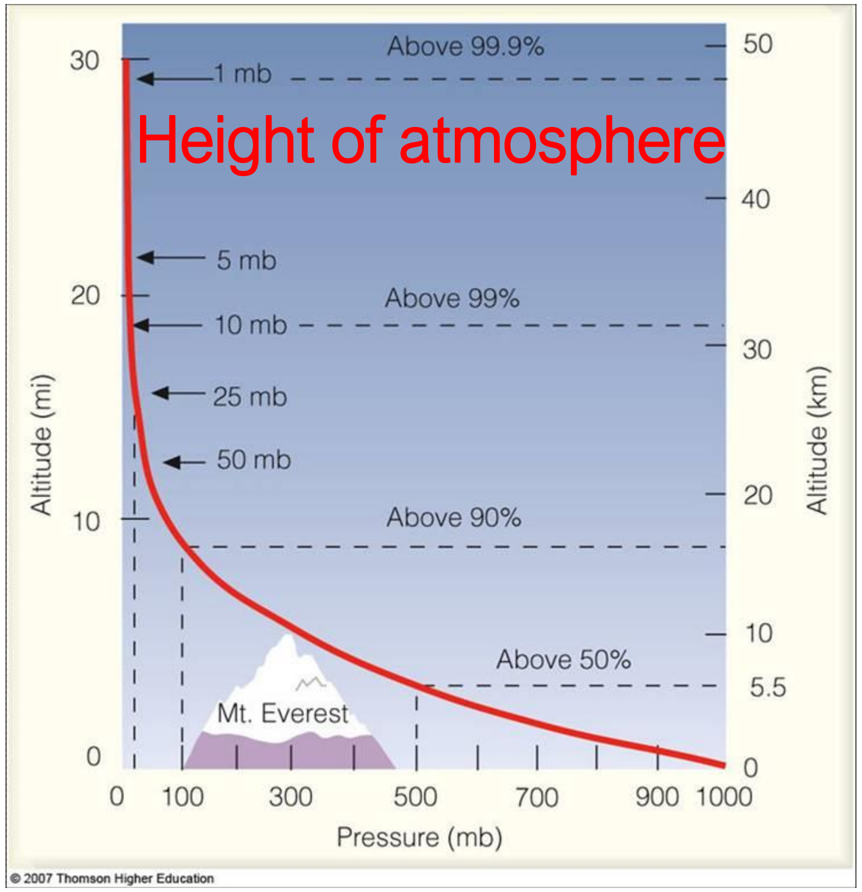


Figure Source: https://sites.psu.edu/musingsofameteorologist/wp-content/uploads/sites/2186/2013/01/pressure-structure-of-atmosphere.jpg

How structure of various proteins is decided?

Protein perform their function by folding into different shapes

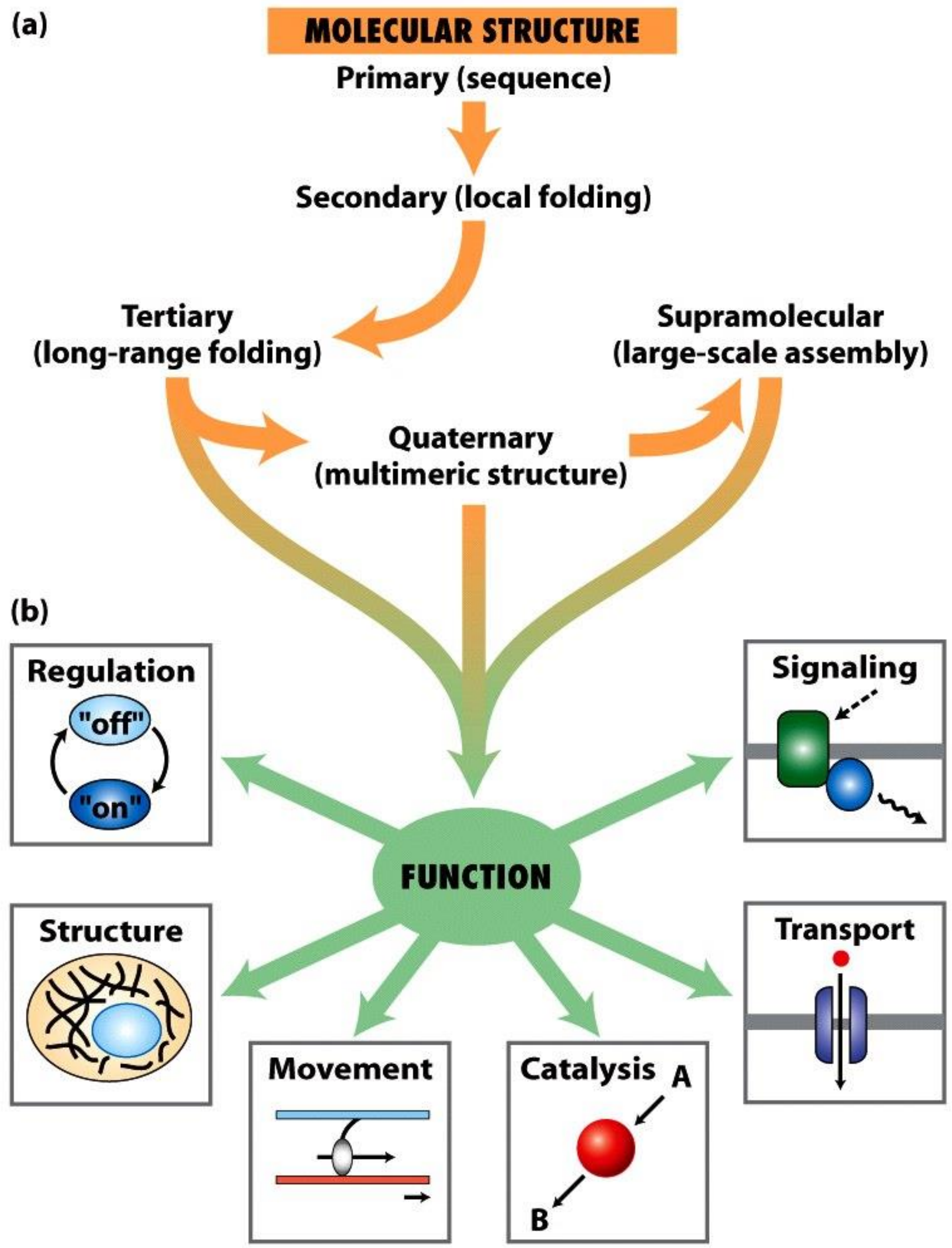


Figure 3-1
Molecular Cell Biology, Sixth Edition

Video Source:http://multimedia.mcb.harvard.edu/

In this module of BB 101 course…

- We will attempt to provide a quantitative description of a few biological systems/phenomena
- Why biological problems are among the most exciting and challenging engineering problems with very interesting science behind them

Let's start with proteins!!!

Sedimentation of a globular protein

What is sedimentation?

Video Source: https://www.youtube.com/watch?v=seFuFG_x-b8

Physical Properties of a globular protein

Property	Value
Mass	166×10^{-24} kg
Density	1.38×10^{3} kg/m^{3}
Volume	120 nm^{3}
Radius	3 nm

Sedimentation of a globular protein of radius 3nm and mass 100 KDa in an Eppendorf tube filled with water upto 1cm height

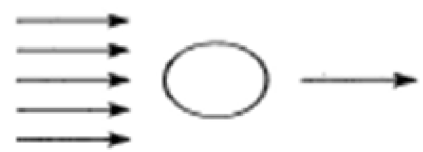
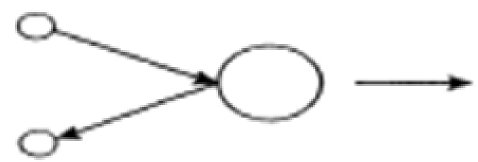
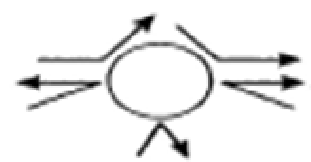
Answer: ~1.2×10^{9} seconds ~ 38.05 years

Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

What is force?

- Force is a push or pull
- Effect on free object (accelerate) and Effect on constrained object (deform)
- Net force is sum of all forces irrespective of their origin
- SI Unit of Force Newton
- What is 1N (weight of ___ gram object)
- Forces at single molecule level are measured in pN
- How small is 1 pN?

Forces acting on a protein molecule

Type of force	Diagram	Approximate magnitude
Elastic		1–100 pN
Viscous		1–1000 pN
Collisional		10^{-12} to 10^{-9} pN for 1 collision/s
Thermal		100–1000 pN
Gravity		10^{-9} pN
Centrifugal		$< 10^{-3}$ pN
Magnetic		$<< 10^{-6}$ pN

Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

Biomolecules and Inertia

- Protein and other biomolecules are so tiny that inertial forces are very small in comparison to viscous forces due to surrounding medium

- Most of the mechanics discussed in standard school Physics text books is irrelevant at molecular and cellular levels as inertial forces are small

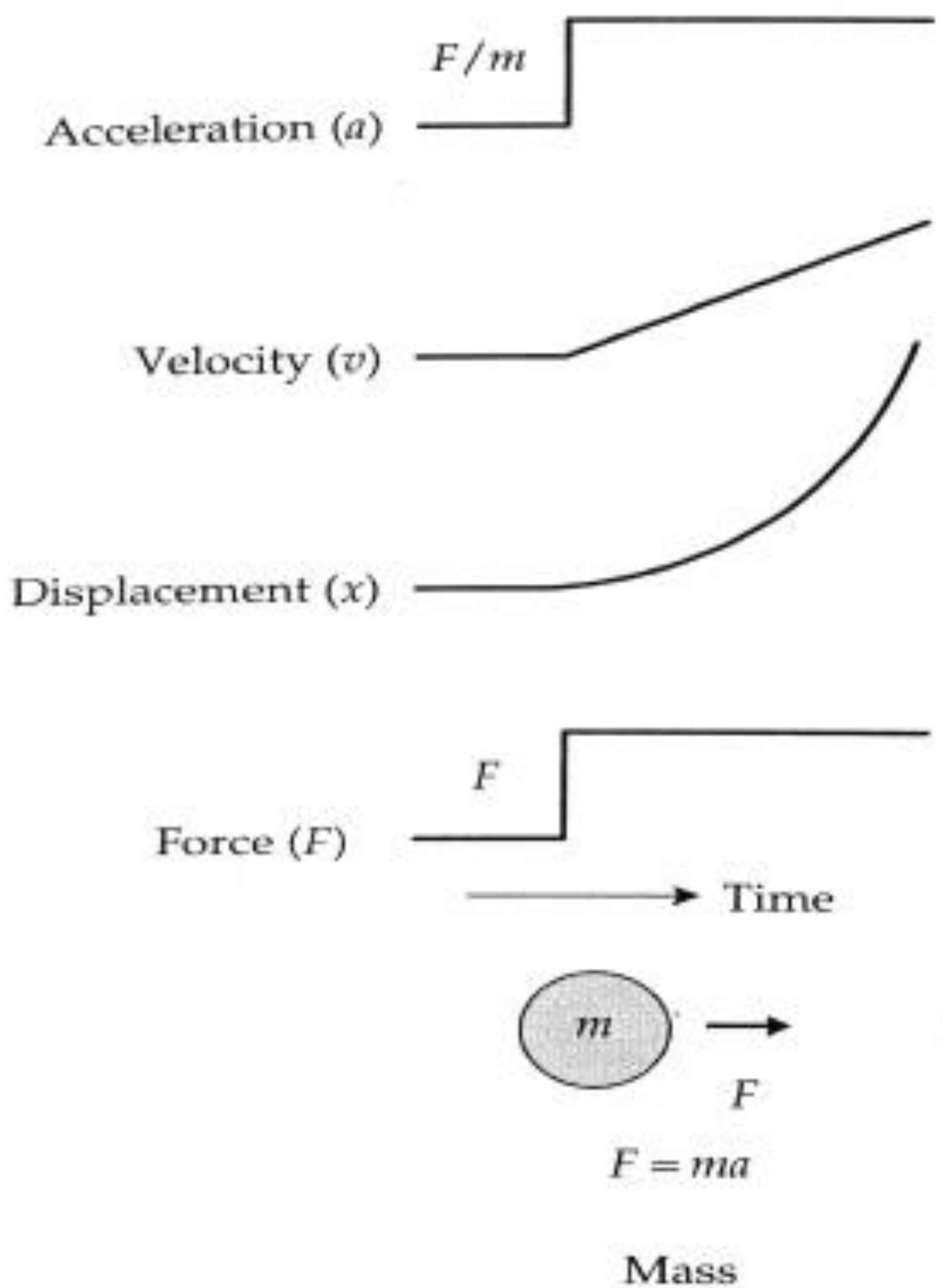
- Since effect of gravity can be ignored
- Oscillatory motions of heavy mass objects such as of that pendulum and planets (which occupy so much of mechanics textbooks) simply do not occur at level of single molecule

- However, we can still use mechanics to understand biological systems

- Some biological systems can be modelled as combinations of three fundamental mechanical elements mass, springs and <u>dashpots</u>

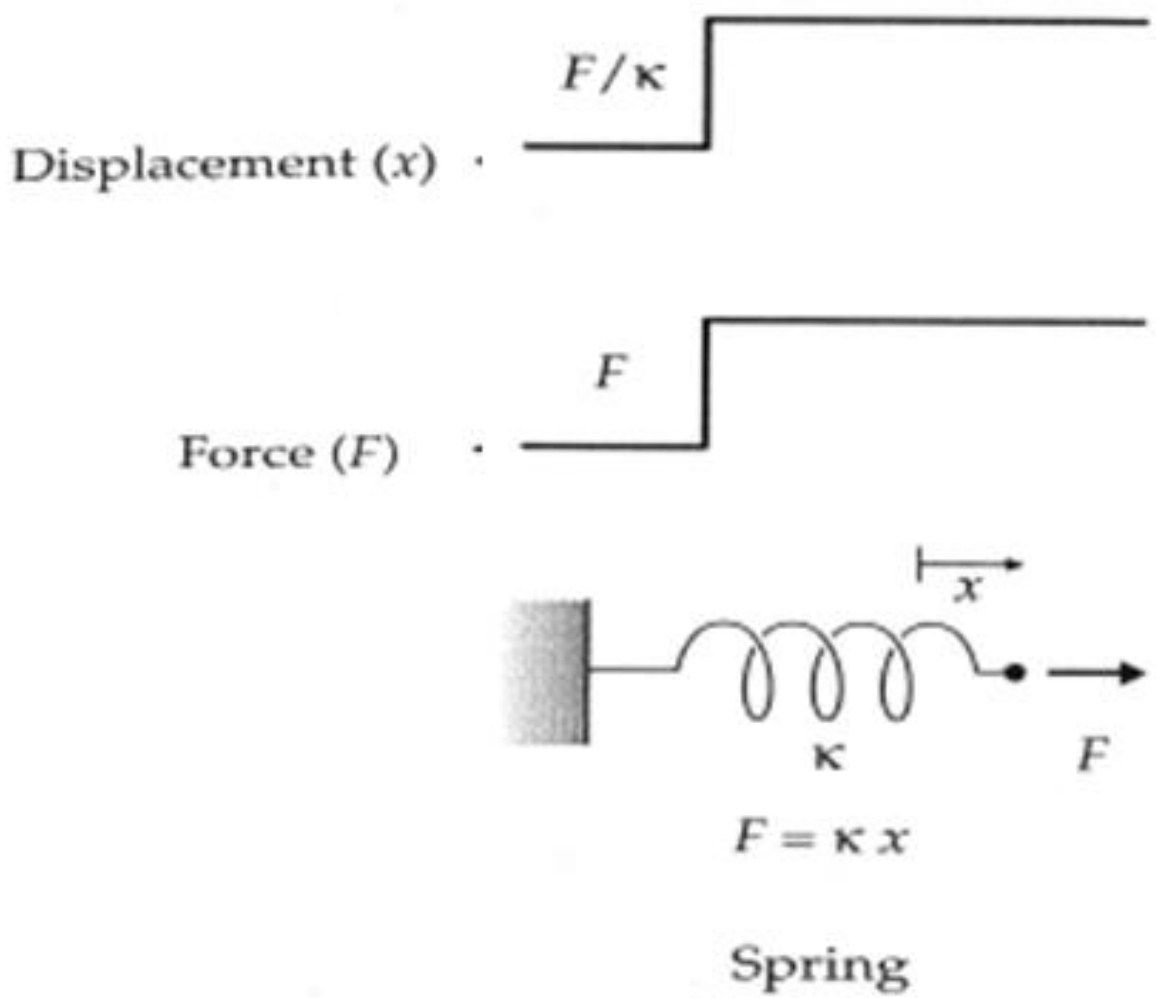
- Let’s review their properties

Motion of Mechanical element: Mass



Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

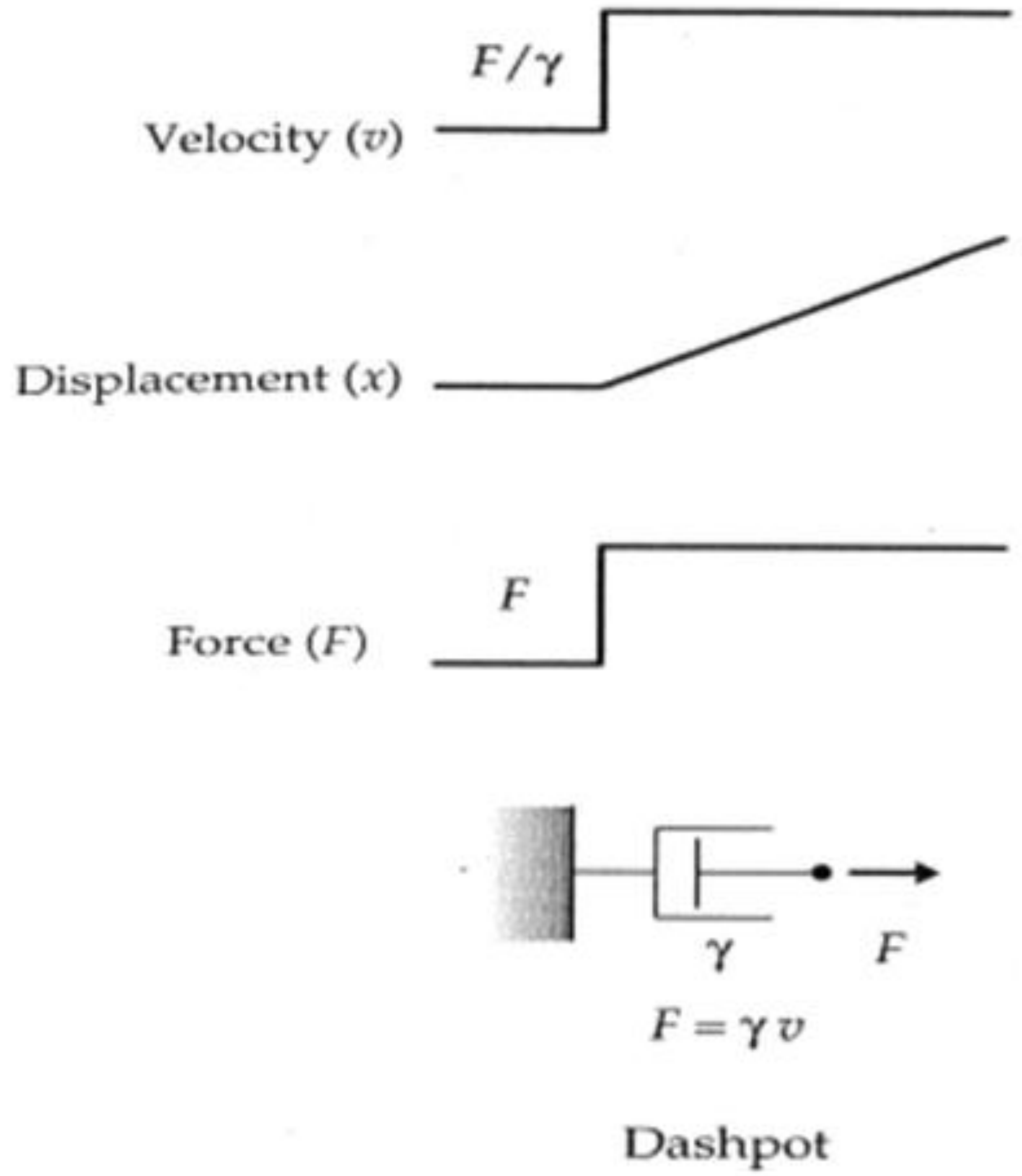
Motion of Mechanical element: Spring



Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

Motion of Mechanical element: Dashpot

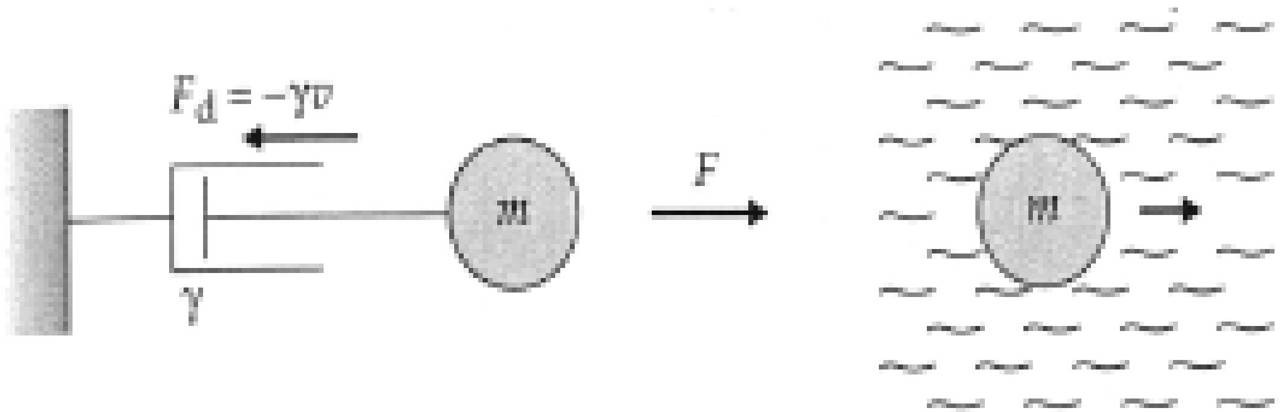
- Responds to force by elongating at constant velocity
- No net force, external force is balanced by drag force
- Dashpot model is used to describe how an object move in fluid
- Strategy: model submerged object connected to dashpot)



Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

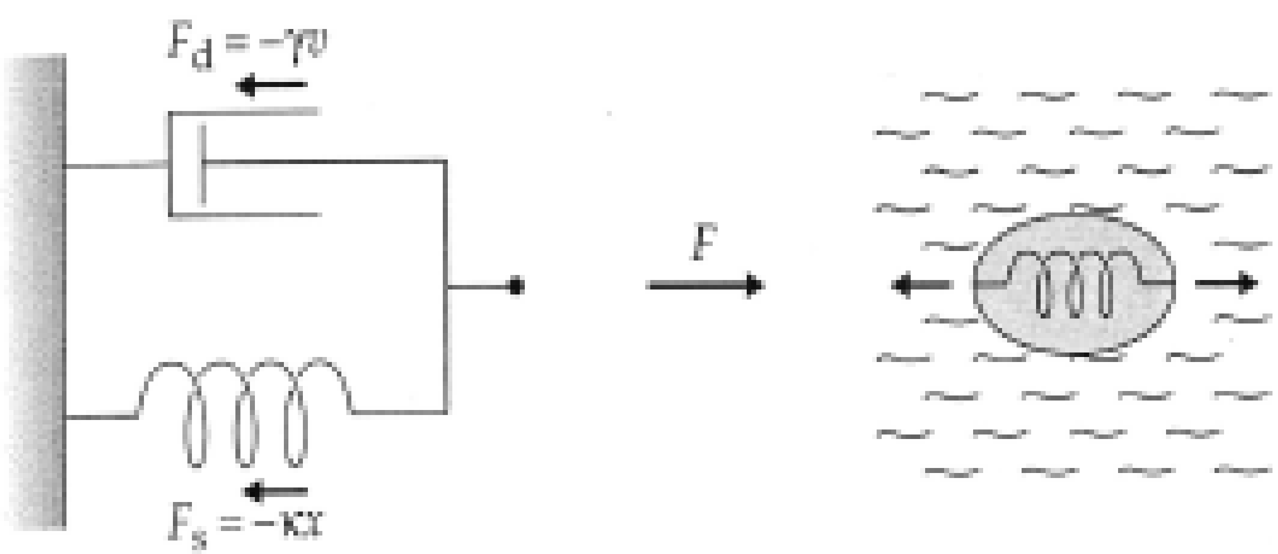
Motion of combination of mechanical elements

(A)



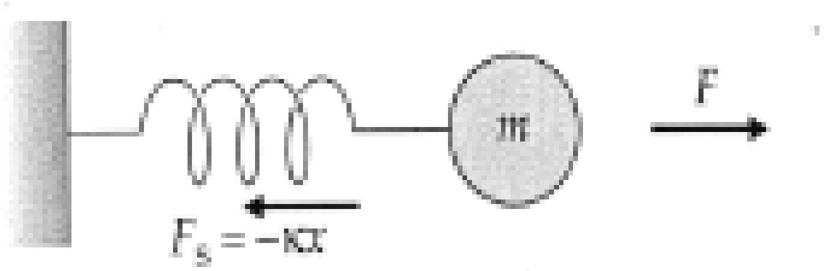
Object damped by viscous fluid

(B)



Low mass object deformed in viscous fluid

(C)



Undamped objects

Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

Motion of combination of mechanical elements

(A) Mass & Dashpot

$$m\frac{dv}{dt} + \gamma v = F$$

$$v(t) = \frac{F}{\gamma}[1 - exp(-\frac{t}{\tau})]$$

(B) Spring & Dashpot

$$\gamma\frac{dx}{dt} + \kappa x = F$$

$$x(t) = \frac{F}{\kappa}[1 - exp(-\frac{t}{\tau})]$$

(c) Mass & Spring

$$m\frac{d^2x}{dt^2} + \kappa x = F$$

$$x(t) = \frac{F}{\kappa}[1 - cos(\omega t)]$$

Source: Mechanics of Motor Proteins and the Cytoskeleton, Jonathan Howard

Inertia of microscopic and macroscopic swimmer

Consider a bacterium swimming through water at a speed of 10 micron/s. How far bacterium will continue to move after its flagellar motors stop working? Assume bacteria to be a sphere of radius 0.5 micron with density 5 times that of water.

Consider a pufferfish swimming through water at a speed of 10 mm/s. How far pufferfish will continue to move after its fins stop working? Assume pufferfish to be a sphere of radius 0.5 mm with density 5 times that of water.

Video Source: https://www.youtube.com/watch?v=a_5FToP_mMY
Video Source: https://www.youtube.com/watch?v=wnzlPwaf7cs

Summary

- *What is Physical Biology/Biophysics?*

- *Proteins molecules and forces acting on protein molecules*

- *Inertial forces are negligible and effect of gravity can be ignored*

- *Many biological systems can be modeled as combination of three fundamental mechanical elements-mass, spring and dashpot.*