**Biophysics I** (BPHS 4080)

**Instructors:** Prof. Christopher Bergevin (cberge@yorku.ca)

**Website:** http://www.yorku.ca/cberge/4080W2018.html
Dissolution and diffusion through lipid bilayer
Transport through water channels
Transport through gated ion channels
Carrier-mediated transport

Intracellular
Membrane
Extracellular

Figure 2.19
Deep Learning
With massive amounts of computational power, machines can now recognize objects and translate speech in real time. Artificial intelligence is finally getting smart.

by Robert D. Hof

https://www.technologyreview.com/s/513696/deep-learning/
A Primer On Deep Learning

The term “artificial intelligence” (AI) has been around since the 1950s, but there has long existed a yawning gap between what people thought AI to be and what was actually possible. Since the 1960s, much of what has been considered to be AI has been a form of machine learning. However, despite the leaps and bounds in technology since the term was first introduced, the accomplishments of machine learning have often fallen short of public expectations (think the robots in The Jetsons).

Fortunately, after a half-century of research, that gap between our expectations and reality is finally closing, thanks to deep learning, a more advanced type of machine learning that’s capable of generating human-like insight. Here, I will give an introduction to deep learning and explore the potential of this groundbreaking new field.
Which of the six boxes below cannot be made from this unfolded box? (There may be more than one.)
What helps prevent disaster here? What sort of ‘signals’ convey the relevant info?

What are the basic biological mechanisms at work here?

What are the basic physical mechanisms at work here?
Neurons

Figure 1.22
York University
BPHS 4080: Biophysics I (3 credits)
Winter 2018

Time & Location
Lecture: MWF 1:30-2:30 (CC 335)

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Office Hours: Check course website (or email for appt.)

Course Website:

Textbook:

Prerequisites: SC/BPHS 2090 2.00; SC/PHYS 2020 3.00; SC/PHYS 2060 3.00

Course Theme/Topics: This course will generally focus on the topic of cellular transport to examine the interplay between physics and the life sciences. Topics will include (but are not limited to):

- Diffusion
- Osmosis
- Carrier-mediated transport
- Ion channels
- Modeling cell membranes using electric circuit analogs
- Action potentials (e.g., Hodgkin Huxley model)
- Nonlinear dynamics
- Synapses, Neural systems

First Day of Class ........................................ Jan. 5
Add Deadline ............................................ Jan. 31
*Midterm Exam* ........................................... Feb. 9
Winter Reading Week ......................... Feb. 19–23 (no classes)
Drop Deadline ............................................. Mar. 9
Good Friday .............................................. Mar. 30 (no class)
Last Day of Class ........................................ Apr. 6
*Final Exam* .............................................. TBD


This is the course website and will be the main “go to” place for all course-related info (e.g., syllabus, slides, chapters for reading, exam info, etc...)
BPHS 4080 Overview

- Diffusion
- Cell membranes
- Osmosis
- Carrier-mediated transport
- Electrical responses of cells
- Resonance
- Electro-diffusion, Resting potential
- Ion pumps
- Core-conductor model
BPHS 4080 Over/Re-view

- Cable model
- Hodgkin-Huxley
- Myelination, saltatory conduction
- Ion channels
4080 Summary: Hodgkin-Huxley Equations

\[
\frac{1}{2\pi a (r_o + r_i)} \frac{\partial^2 V_m}{\partial z^2} = C_m \frac{\partial V_m}{\partial t} + G_K(V_m, t) (V_m - V_K) + G_{Na}(V_m, t) (V_m - V_{Na}) + G_L(V_m - V_L)
\]

\[
G_K(V_m, t) = \overline{G}_K n^4(V_m, t)
\]
\[
G_{Na}(V_m, t) = \overline{G}_{Na} m^3(V_m, t) h(V_m, t)
\]
\[
n(V_m, t) + \tau_n(V_m) \frac{dn(V_m, t)}{dt} = n_\infty(V_m)
\]
\[
m(V_m, t) + \tau_m(V_m) \frac{dm(V_m, t)}{dt} = m_\infty(V_m)
\]
\[
h(V_m, t) + \tau_h(V_m) \frac{dh(V_m, t)}{dt} = h_\infty(V_m)
\]

Nernst Equilibrium Potential
\[
V_n = \frac{RT}{z_n F} \ln \frac{c_n(d)}{c_n(0)} = \frac{RT}{z_n F} \ln \frac{c_n^a}{c_n}
\]
\[
G_n = \int_0^d \frac{1}{u_n z_n^2 F^2 c_n(x)} \geq 0
\]

\[
\tau_x \frac{dx}{dt} + x = x_\infty \quad \frac{dx}{dt} = \alpha_x (1 - x) - \beta_x x
\]
\[
x_\infty = \frac{\alpha_x}{(\alpha_x + \beta_x)} \text{ and } \tau_x = 1/(\alpha_x + \beta_x)
\]
\[
\alpha_x = \frac{-0.1(V_m + 35)}{e^{-0.1(V_m+35)} - 1},
\]
\[
\beta_x = 4e^{-(V_m+60)/18},
\]
\[
\alpha_h = 0.07e^{-0.05(V_m+60)},
\]
\[
\beta_h = \frac{1}{1 + e^{-0.1(V_m+30)}},
\]
\[
\alpha_n = \frac{-0.01(V_m + 50)}{e^{-0.1(V_m+50)} - 1},
\]
\[
\beta_n = 0.125e^{-0.0125(V_m+60)},
\]

Weiss (1996)
Biophysically, this figure encapsulates numerous key ideas....
Describing biological/physiological systems

Qualitative [words]

Quantitative [numbers]

Analytical [equations]

e.g. statistics
e.g. mathematical models
e.g. numerical computations
Figure 2.19

Dissolution and diffusion through lipid bilayer

Transport through water channels

Transport through gated ion channels

Carrier-mediated transport

Pumps

Intracellular

Membrane

Extracellular
Ex. Eating a potato

**Escherichia Coli (E. Coli)**

<table>
<thead>
<tr>
<th>Culture Medium</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₄Cl</td>
<td>1.0 g</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>0.13 g</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>3.0 g</td>
</tr>
<tr>
<td>Na₂HPO₄</td>
<td>6.0 g</td>
</tr>
<tr>
<td>Glucose</td>
<td>4.0 g</td>
</tr>
<tr>
<td>Water</td>
<td>1.0 L</td>
</tr>
</tbody>
</table>

**Generic Eukaryotic Animal Cell**

**Culture Medium**

- **Essential Amino Acids** (a dozen)
- **Vitamins** (eight)
- **Salts** (Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, PO₄³⁻, HCO₃⁻)
- **Glucose**
- **Serum**

**Inputs to Organism**

- air
- water
- food
  - carbohydrates
  - fats
  - proteins

**Inputs to Cells**

- oxygen
- water
- ions
- building block molecules
  - sugars
  - lipids
  - amino acids
Functions of more than one variable

⇒ will be important for the various types of systems we will be describing analytically in the course

e.g. concentration of a solute in a solution \((c)\) depends upon both spatial location \((x)\) and time \((t)\)

\[ f = f(x, y) \]

\( f \) - dependent variable

\( x, y \) - independent variables
\[ f(x, y) = (1 - x) = f(x) \]
\[ f(x, y) = (1 - y) = f(y) \]
**Biological Context**

\[ f \] - reaction rate \([mol/s]\)

\[ x, y \] - concentration of inhibitor agents \([mol]\)

\[
 f(x, y) = k(1 - x)(1 - y)
\]

\[
 [k] = \frac{1}{mol \cdot s}
\]

don’t forget about units!
can you think of an example of what the various variables might represent?

\[ f(x, y) = y \cos(2\pi x) \]
solution to diffusion equation (or heat eqn.)

\[ f(x, y) = \frac{1}{\sqrt{y}} e^{-x^2/y} \]
Differentiation of functions of more than one variable

Derivative (definition) for a function of a single variable

\[ \frac{dg(x)}{dx} = \lim_{\Delta x \to 0} \frac{g(x + \Delta x) - g(x)}{\Delta x} \]

For multi-variable function, keep one variable constant

\[ \frac{\partial f(x, y)}{\partial x} = \lim_{\Delta x \to 0} \frac{f(x + \Delta x, y) - f(x, y)}{\Delta x} \]

Note difference in notation

\( y \) is effectively held constant here
Differentiation of functions of more than one variable

Can also take partial deriv. with respect to partial deriv.

\[ \frac{\partial}{\partial y} \left( \frac{\partial f}{\partial x} \right) \]

Simplified notation

\[ \frac{\partial}{\partial y} \left( \frac{\partial f}{\partial x} \right) = \frac{\partial}{\partial y} (f_x) = (f_x)_y = f_{xy} \]
Differentiation of functions of more than one variable

Examples:

ex. 1 \[ \frac{\partial z}{\partial x} \quad \text{for} \quad z(x, y) = (xy)^{1/2} \]

\[ \frac{\partial z}{\partial x} = \frac{1}{2} \cdot y^{1/2} \cdot x^{-1/2} \]

ex. 2 \[ \frac{\partial}{\partial b} \left( \frac{\partial \phi}{\partial a} \right) \quad \text{for} \quad \phi(a, b) = ab^2 + 3a^2e^b \]

Notation: \[ \frac{\partial}{\partial b} \left( \frac{\partial \phi}{\partial a} \right) = \frac{\partial}{\partial b} (\phi_a) = (\phi_a)_b = \phi_{ab} \]

First find \( \phi_a \) (assume \( b \) is constant): \( \phi_a = b^2 + 6ae^b \)

Now differentiate with respect to \( b \): \( \phi_{ab} = \frac{\partial}{\partial b} (\phi_a) = 2b + 6ae^b \)

Note: In this case \( \phi_{ab} = \phi_{ba} \) which is true for continuous functions (i.e. order of differentiation doesn’t matter)
Differential equations

**ODE (‘ordinary’):** considers a function of one variable and how it changes with respect to that variable

\[ \frac{dc}{dt} = kc \quad \text{where} \quad c = c(t) \quad \text{and} \quad k = \text{const}. \]

**PDE (‘partial’):** considers a function of more than one variable and how its various partial derivatives are related

\[ \frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad \text{where} \quad c = c(x, t) \quad \text{and} \quad D = \text{const}. \]
Solving an ODE: find $c(t)$ for \[ \frac{dc}{dt} = kc \]

1. Separate variables and integrate
   \[
   \int \frac{dc}{c} = \int k \, dt
   \]
   \[
   \Rightarrow c(t) = Ae^{kt}
   \]

2. Use an initial condition to find a unique solution. Suppose we have
   \[
   c(1/k) = \frac{\ln(e^e)}{3}
   \]
   \[
   c(t) = \frac{e^{kt}}{3}
   \]
Brownian motion
Diffusion

Each particle undergoes Brownian motion.
Diffusion (1-D)

- Thomas Graham (Scottish chemist, ~1828-1833)
  [pioneered the concept of dialysis]

- Adolf Fick (German physiologist, ~1855)
  [actually was the first to successfully put a contact lens on a person in 1888!]
“A few years ago, Graham published an extensive investigation on the diffusion of salts in water, in which he more especially compared the diffusibility of different salts. It appears to me a matter of regret, however, that in such an exceedingly valuable and extensive investigation, the development of a fundamental law, for the operation of diffusion in a single element of space, was neglected, and I have therefore endeavoured to supply this omission.”

- A. Fick (1855)