Physics 555, Modern Biophysics.
Winter Term 1 (Sept– Dec 2025): Schedule, Learning Goals, Homework

Text: Physical Biology of the Cell (2nd edition), by Rob Phillips, Jane Kondev, Julie Theriot, and Hernan Garcia.
See Canvas for learning modules and lecture material

Week	Textbook Sections	Major Learning Goals
Week 1 HW 1	Intro to Phys 555 13.1 Diffusion in the cell 13.2 Concentration fields and diffusive flux	• Understand the microscopic origins of friction • Understand the relationship between friction and the diffusion coefficient • Write a microscopic expression for the diffusion coefficient • Write and explain Fick's law • Relate the thermal velocity of particles in solution to their temperature • Write and understand the Einstein equation relating the friction coefficient, diffusion constant, and the temperature • Understand the Reynolds number, and when it is small or large • Using dimensional analysis to find the relationship between the frictional drag force on a moving sphere
Week 2 HW 2	13.2 The diffusion equation 13.2.1 Diffusion by summing over microtrajectories 13.2.5 The Einstein relation 8.2.1 Random walk combinatorics 2.1 (pp 44-48) Binomial probabilities 8.2.4 Return probability for random walks – dimension dependence	• Understand dimensional analysis and how to derive Stoke's law • Understand the Gibbs-Boltzmann equation • Distinguish diffusive from drift flux and write equations for each • Derive the Einstein relation • Estimate diffusion coefficients of molecules • Derive the diffusion equation from continuity and from microtrajectories • Understand and use binomial probability distributions • Probability distributions of random walkers for a large number of steps, in 1D, 2D, 3D. • Diffusion time • Biopolymer configurations as random walks • Return probability and probability of contact formation
Week 3 HW 3	14.2.4 (pp 561-562) Self-avoiding polymers 8.3.2 Force-extension curves 13.2.3 Diffusion in the cell--FRAP	• Force-extension relationships for stretched polymers • Scaling law for the size of a stretched polymer • Scaling law for stretched polymers • Understand the boundary conditions of confined particles vs. confined polymer distributions • Confined polymers; DNA conformations in the nucleus • Fluorescence Recovery After Photobleaching (FRAP); Fourier expansion solutions of the diffusion equation

Week 4 HW 4	13.3.1 Diffusion to capture, cell signaling, receptors 10.1, 10.2 Beams are everywhere: From flagella to the cytoskeleton; Geometry and energetics of beam deformation 10.1, 10.2: Geometry and energetics of beam deformation 8.2.2. 8.2.3: Size of the genome, genetic maps and physical maps of chromosome structure	• Diffusion to capture and perfect absorbers • Systems of reacting particles • Elastic Properties of polymers and cellular components • Young's modulus, curvature, minimum energy conformations • Minimum energy conformations; • Persistence length of polymers • The worm-like chain • Composition, mechanical properties, and structure of chromatin • Global structure of chromatin and the crumpled globule
Week 5 HW 5	6.1: Statistical mechanics; A first look at ligand receptor binding 6.1.2: Statistical mechanics of gene expression, RNA polymerase binding to promoter sequences 6.1.3: The Gibbs Boltzmann distribution 6.1.5: Boltzmann distribution by best guess with limited information 5.5.2, 5.5.3: Thermal and chemical equlibrium are obtained by maximizing the entropy	• Gibbs-Boltzmann formula; Statistical mechanics of ligand-receptor binding • Free energy and the partition function • Chemical potential • Connecting thermodynamics with statistical mechanics • Microstates and macrostates • Promoter binding and transcription • Most likely distributions; Maximizing the Shannon entropy
Week 6 HW 6	6.1.2: Statistical mechanics of gene expression: RNA polymerase and promoter 19.1, 19.2.1 pages 813-814: Gene regulation and activators 6.2.2: Free energy of dilute solutions	• Pol II binding to promoters; probability of binding • Tethered activators and gene regulation • Fold change (FC) and the regulatory factor F_{reg} • Chemical potential; Gibbs-Duhem equation; • Entropy of mixing
Week 7 **Evening Midterm** HW 7	6.2.2: Free energy of dilute solutions 6.2.3: Osmotic pressure as an entropic spring 6.3: The calculus of equilibrium applied: The law of mass action 6.4.1: A second look at ligand-receptor binding 7.2.1 The Gibbs Distribution: Contact with a particle reservoir 7.2.2 Simple ligand-receptor binding revisited 6.4.3: Beyond simple ligand receptor binding: The Hill function	• Understand the law of mass action in chemical equilibrium • Understand osmotic pressure from the chemical potential • Grand canonical ensemble • Chemical potential in ligand binding • Hill functions; binding cooperativity • Condensates in mixtures; liquid-liquid phase separation • Phase separation in transcription; super-enhancers

Week 8 HW 8 **Interview**	6.4.3: Beyond simple ligand receptor binding: The Hill function 6.4.4: ATP power 15.2.4: Bimolecular reactions 15.2.7: Michaelis-Menton and enzyme kinetics	• Hill functions; binding cooperativity • Understand law of mass action applied to ATP hydrolysis; Concentration-dependence of free energy change of a reaction • Statistical mechanics and Chemical kinetics: Derivation of bimolecular rate equations and dissociation constants • Bimolecular rate equations and dissociation constants contd. • Understand and implement the Michaelis-Menton reaction
Week 9 HW 9	19.1: Chemical and informational organization in the cell 19.2.1: The molecular implementation of regulation: Promoters, activators, and repressors 19.2 (all subsections): Genetic Networks: Doing the right thing at the right time	• Gene regulation review; The regulatory factor F_{reg} for an activator. • The regulatory factor F_{reg} for an activator and for a repressor; Fold change FC for an activator and repressor. • Activators and repressors; The Lac operon and DNA looping in regulation. • DNA looping in repression; Nucleosome remodeling in gene regulation
11: Week 10 HW 10 **Interview**	20.2.3 Spatial regulation 19.3.1: The dynamics of RNA polymerase and the promoter 19.3.2: Dynamics of RNA Distributions 19.3.3: Dynamics of regulated promoters	• Cooperative regulation of Hb by Bcd; precision in spatial expression patterns • Dynamics of transcription by the numbers; Mean and variance of mRNA expression levels • The Gillespie algorithm and stochastic models of gene regulation
Week 11 HW 11	19.3.5: Genetic switches, natural and synthetic 19.4 Cell Signalling 20.2 Morphogen gradients; The French Flag model 20.3 Reaction-Diffusion and Spatial patterns	• Understand stability points in phase portraits; vector fields • Linear stability analysis for the genetic switch • Genetic oscillators • Ligand receptor binding in cell signaling • Anterior-Posterior patterning • Turing patterns
Week 12 HW 12 **Interview**	20.4 Somitogenesis 20.5 Lateral inhibition 21. 2 Gene structure; multiple sequence alignment Genome structure	• Vertebral segment formation • Notch-delta signaling • Genome structure • Phylogenetic trees; evolutionary mechanisms