Fall 2020 **BioE103: Engineering Molecules II** **Gerard Marriott**

Syllabus

Midterms and Final Exam dates also subject to minor changes

August 26th 2020

Lecture 1: Introduction to the course:
Expected learning outcomes
Organization of lectures and subject content
Homework, midterms and grading
Overview of the course: Thermodynamics, Inter-molecular Forces, Spectroscopy, Binding and Reaction kinetics, Enzyme kinetics

Lecture 2 Thermodynamics
Properties of Ideal Gases
Gas Laws: Equations of state
Partial pressures: Mixtures of gases
Definitions and glossary of thermodynamic terms

August 28th 2020
Lectures 3a and 3b Thermodynamics
Derivation of expressions in the kinetic molecular theory
Root mean squared velocity of gas molecule motion
Maxwell-Boltzmann distribution of velocities – meaning of velocity terms
The Boltzmann constant, Temperature and the Internal Energy of a system
Collisions and mean free path
Kinetic energy, temperature and Internal energy of gases

August 31st 2020
Lecture 4 Thermodynamics
Energy, Work and Heat
Ideal Gas Thermometer
The Kelvin scale and absolute zero temperature
Van der Waal’s equations of state for Real gases

September 2nd 2020
Lecture 5 Thermodynamics
First law of thermodynamics

Systems and their surroundings
State variables and State Functions
Internal Energy
Expansion against constant pressure
Reversible and irreversible expansion
Isothermal Reversible expansion of an ideal gas
Cyclical processes: Heat machines

September 4th 2020
Lecture 6 Thermodynamics
Energy Transactions in thermodynamic systems
What happens when you heat atoms and molecules
Distribution of energy in translational, rotational and vibrations states.
The equipartition theorem – derivation
Worked example of the partition of energy in vibrational states of Iodine gas

Release of Homework #1

September 7th 2020 **Labor Day – no lecture**

September 9th 2020
Lecture 7 Thermodynamics
Heat capacity, constant volume and constant pressure, including their derivations.
Adiabatic processes:
Derivation of the PV relationship for adiabatic processes

September 11th 2020
Lecture 8 Thermodynamics
Enthalpy
Calorimetry
Thermochemistry
Hess' Law

Homework #1 due before class

September 14th 2020
Lecture 9 Thermodynamics
On reversibility and irreversibility – the arrow of time
The Second Law of thermodynamics
Entropy as a state function

Carnot Engine and the Carnot cycle

September 16th 2020
Lecture 10 Thermodynamics
Clausius inequality
Entropy changes in isolated systems: mixing, expansion and thermal equilibration
The third Law of thermodynamics
Absolute measurements of entropy

September 18th 2020
Lecture 11 Thermodynamics
Gibbs free energy
Gibbs free energy properties with temperature and pressure
Partial molar volume and Partial molar Gibbs energies
Maximum non-expansion work
Free energy change and the equilibrium constant

September 21st 2020
Lecture 12 Thermodynamics
Statistical thermodynamics
Postulates and definitions
Calculations of Macrostates and Microstates for large numbers of states
Stirling's approximation (and a derivation of Stirling's approximation for those interested)
Equivalence of macroscopic and microscopic considerations of entropy
Boltzmann entropy

Release Homework #2

September 23st 2020
Lecture 13 Thermodynamics
Chemical potential
Chemiosmotic theory

September 25th 2020
Lecture 14 Thermodynamics
Equilibria
Equilibrium constants
Energetics and Chemical Equilibria
Select examples relevant to Bioengineering

September 28th 2020
Lecture 15 Inter-molecular Forces I
Electric Dipoles in gases, solvents and proteins
Ion-ion interactions

Homework #2 due before class

September 30th 2020
Lecture 16 Inter-molecular Forces II
Ion-dipole interactions
dipole-dipole interactions
dipole-induced dipole interactions
Dispersion forces
van der Waals interactions

October 2nd 2020
Lecture 17 Inter-molecular Forces III
Hydrogen bonding
Intermolecular forces and protein conformation
Select examples relevant to Bioengineering

October 5th 2020
Lecture 18 Inter-molecular Forces IV
Protein structure
Protein folding and unfolding
Physicochemical properties of the protein matrix

Release Homework #3

October 7th 2020
Lecture 19 Spectroscopy
Interaction of light with matter
Bonding and anti-bonding orbitals in organic molecules
LUMO and HOMO
Transitions between states: Rotational, Vibrational and electronic
Particle in a 1-D box
Optically-induced transitions in Biomolecules

October 9th 2020

Lecture 20: Spectroscopy

Absorption

Derivation of the Beer-Lambert Law

Absorption of natural pigments

Human vision

Select applications in Bioengineering

October 12th. 2020

Lecture 21: Spectroscopy

Fluorescence spectroscopy

Properties of the excited state

Perrin-Jablonski Diagram

Emission spectra

Instrumentation

Homework #3 due before class

October 14th. 2020

Lecture 22 Spectroscopy

Dynamic properties of the excited states of ions and molecules

Derivation of rates of decay of excited states:

Fluorescence Lifetime

Derivation of expressions for exponential decay of excited states

Origins of single and multiple exponential decay of the excited state

October 16th 2020

Lecture 23 Spectroscopy

Static and dynamic quenching of excited states

Derivation of the Stern-Volmer equation

Applications of quenching

Protein topology and molecular environments

Triplet states and phosphorescence emission

Select applications in Bioengineering: Optical-based sensing of oxygen

October 19th 2020

Lecture 24 Spectroscopy

Design and performance of organic and inorganic optical probes and biosensors

Nanoparticles

Qdots, Phosphors and Mechanoluminophores

Select applications in Bioengineering
Release mid-term Exam

October 21st 2020
Lecture 25 Spectroscopy
Genetically-encoded fluorescent proteins
Photochemistry
Photophysics
Select applications in Bioengineering

October 23rd 2020
Lecture 26 Spectroscopy
Rotational properties of biomolecules and their complexes
Polarisation and anisotropy
Perrin equation
Instrumentation
Absorption and emission dipole moments
Molecular tumbling rates and their measurement using fluorescence anisotropy
Applications relevant to Bioengineering

October 26th. 2020
Lecture 27: Spectroscopy
Foerster resonance energy transfer I
Dipole-dipole interactions in biomolecules
Non-radiative transfer of energy between dipoles
Orientation, overlap integral, quantum yield and lifetime
Calculations of distance using different orientations of dipoles

a), Midterm exam due before class
b), Final exam topics released
– you will have plenty of time to think about your scholarly-written article

October28th. 2020
Lecture 28: Microscopy
Part 1: Foerster resonance energy transfer II
Applications relevant to Bioengineering
Part 2: Optical Microscopy
Optical resolution in the microscope

Release Homework 4

October 30th. 2020

Lecture 29: Microscopy

Single molecule Imaging

Confocal microscopy (1-photon and 2-photon)

Total internal reflection imaging microscopy" protein activity in cells

Fluorescence correlation spectroscopy/microscopy: protein interactions

Applications relevant to Bioengineering: Molecular motors

Actomyosin, Kinesin and F_0/F_1-ATPase

November 2nd. 2020

Lecture 30: Microscopy

Super-resolution Imaging microscopy

Single molecule imaging techniques: PALM/ fPALM and STORM

Ensemble approaches: STED

Applications relevant to Bioengineering: Dynamics in nuclear membrane protein pores

November 4th. 2020

Lecture 31: Binding and Kinetic reactions

Interactions between molecules: reversible and irreversible

Uni-molecular interactions

Derivation of equations for reversible and irreversible uni-molecular interactions

Homework # 4 due before class

November 6th. 2020

Lecture 32: Binding and Kinetic reactions

Reversible and irreversible Bi-molecular interactions

Derivation of equations for reversible and irreversible reactions

November 9th. 2020

Lecture 33: Binding and Kinetic reactions

Molecularity

Reaction rates

Temperature effects on reaction rates

Rate Laws

Integrated rate laws for uni- and bi-molecular reactions

November 11th. 2020
UC Administrative Holiday: No Lecture

November 13th. 2020
Lecture 34: Binding and Kinetic reactions
Derivations of rate laws for parallel and consecutive reactions
Experimental approaches to study reaction kinetics
Transient kinetic methods: T-jump, P-jump, stopped-flow, photochemical approaches
Applications relevant to Bioengineering

Release homework # 5

November 16th. 2020
Lecture 35: Enzyme Kinetics
Overview
Binding and kinetic reactions in enzymes
Inhibitors and activators
Cyclical pathways, reversibility and work output
Applications relevant to Bioengineering

November 18th. 2020
Lecture 36: Enzyme Kinetics
Michaelis-Menten equation
Derivations of MM and other equations
Plotting kinetic data

November 20th. 2020
Lecture 37: Enzyme Kinetics
Case studies relevant to Bioengineering

November 23rd. 2020
Lecture 38: Wrap-up

Homework #5 due before class

November 25~27th. 2020 Thanksgiving Week: No Lecture

Final exam due date TBD