Introductory Physics in Biological Context
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The following is a proposed future syllabus based on the present syllabi actually used at Minnesota and Swarthmore, with some changes for the future incorporated. It includes a little too much material for a 1-year course so each institution will reduce the amount of material covered according to the instructor's preferences.
Biological contexts are provided in parentheses, except for a few lettered sub-topics.

Unit 1: Interactions and their consequences

Section 1. How physics relates to biology

1. Introduction: course is about the "biological consequences of physics"
    a. purpose of physics/core skill of physicists: identify and describe the unifying principles underlying the complexities of living systems (distinguish these principles from system-specific details)
    b. consequences of interactions: conservation and dynamics
    c. get down to the molecular level for mechanisms because so much of biology is molecular
    d. analytical strategies: distinguish system and surroundings; recognize repeating cycles; identify most appropriate scale, build conceptual and quantitative models and make the approximations necessary to predict observed behavior.
    e. observations vs. inferences
    f. nature of expert knowledge, problem solving and decision-making
    g. how this book is organized
2. The physicist's toolbox: models, measurement, and estimation
    a. Interpreting numbers: Units, dimensional analysis, estimation, uncertainties/errors
    b. The power of quantitative relationships: Scaling laws

Section 2. Balanced systems: mechanical equilibrium

3. Balanced forces in one dimension (contexts: molecular force generation by actin/myosin; buoyancy control in underwater animals)

    a. Classifying types of forces: what do students think are forces? How do you tell what is and what is not a force? Start with idea of an interaction, give examples that everyone will agree on: gravitational force, contact forces (pushes and pulls), frictional force, buoyant forces; revisit defining systems
    b. Quantifying how forces work: Newton's laws (include examples of all enumerated forces, all in one dimension)
    c. Directionality of forces, free-body diagrams, introduce vectors in one dimension

4. Balanced forces in two or three dimensions

   a. Newton's laws in two or three dimensions (balanced forces);
   b. Vector algebra and finding vector components
   c. More Newton's laws: Independence of vector components

5. **5.** Balanced forces and torques (contexts: hip joint or similar joint problem)
   a. Defining torque; the cross product
   b. Equilibrium (statics) involving both forces and torques
   c. key ideas: forces are significantly greater than the weights involved and the angle of application is critically important
6. **6.** Balance in materials: solids, fluids, and interfaces
   a. Solids: springs/Hooke's Law; tension in 1D ideal ropes; optional section on stress, strain, and Young's modulus and elastic rods and membranes (forces involved in bending of DNA, cell membranes)
   b. Fluids: pressure (organism height and blood pressure in animals; breathing through a snorkel; pressure-dependent solubility of gases in liquids as a clearly optional section)
   c. Interfaces: surface tension, Laplace's Law, adhesion/capillarity (vascular systems in trees), surfactants (pressures in lung alveoli, pulmonary surfactant)

Section 3. Changing systems: energy and motion

7. Conservation of energy (Motion of a bird or fish or bacterium through fluid; macroscopic and microscopic energy)
   a. What is energy? Enumerate conceptually types of energy relevant to biology that students will have heard about or will hear about in the future: mechanical energy, chemical energy, thermal energy, electromagnetic energy (includes light!)
   b. Energy can be transferred between objects and/or converted between forms, but not destroyed
   c. Conservation theories (mass, atoms, and charge in chemistry)
   d. Defining system/surroundings as essential to tracking energy

8. Mechanical energy and work
   a. Kinetic energy: introduce 1D motion with constant velocity
   b. Energy transfer caused by forces: force components, define work, introduce scalar product
   c. Rate of change of energy due to mechanical work; power
   d. Internal energy in system: gravitational potential energy, general idea of a potential energy associated with a conservative force, identify thermal and chemical energy as "internal" energies

e. Dissipation of mechanical energy into thermal energy via friction
f. Fluid dynamics: conservation of energy in fluid flow. Assume incompressible laminar flow
   • nonviscous: Bernoulli's equation and other hydrodynamic relations (blood flow in circulatory system, pressures in moving fluids; blood needs to flow slowly through capillaries for oxygen to have time to diffuse; sponges maintain flow of water through via height, also termite mounds (McKay))
   • viscous: Hagen-Poiseuille (effect of constriction of blood vessels on blood pressure)

9. Determining how motion changes: one dimension
   a. Newton's second law and acceleration in one dimension (locomotion)
   b. Free fall and terminal velocity
   c. Simple harmonic motion in one dimension (optical tweezers)
   d. Simple harmonic oscillator as model for all kinds of other physical systems

10. Determining how motion changes: more than one dimension
   a. Circular motion (ultracentrifugation, gravity simulators)
   b. Parabolic motion (some nice Vogel examples of biological projectile motion in presence or absence of friction: seeding strategies, fleas jumping, spores)

Section 3. How energy drives change

11. Energy and thermal processes
   a. Energy and temperature (calorimetry, biological effects of environmental temperature)
   b. Energy and phase change (calorimetry, sweat and evaporative cooling, freezing and thawing)
   c. Heat: energy transfer (dynamic temperature stability, descriptions of processes that are independent of mechanisms)
   d. Mechanisms of heat (connecting a general macroscopic process to microscopic mechanisms)

12. Thermodynamic cycles
   a. Energy transfer, systems, and cyclic processes (similarity of heat engines and biological cycles)
   b. Reversible and non-reversible processes

13. Entropy, statistics, and free energy (diffusion, osmotic pressure, protein coiling)

Unit Two: Electricity, magnetism, and light

Section 4. Radiation and light: Energy and information

14. Energy transfer and conversion at the atomic, molecular, and nuclear level

a. Atomic structure (brief mention of Coulomb interaction)

b. Quantization of atomic and molecular energy levels, electronic, rotational, and vibrational energy states

c. Photons: absorption and emission of radiation, energy spectrum (spectroscopy as probe of molecular structure; fluorescence as tool for biological imaging; X-ray imaging contrast from atomic number)

d. Nuclear processes, energy scales of emitted particles, compare to photon energy spectrum

e. "Ionizing radiation" and effects on biomolecules; can be either photons or massive energetic particles (ultraviolet light damaging DNA, cancer radiation treatments)

15. Interactions and light - reflection and refraction of light (theme: heading to vision)

a. Ray model, images and blocking light (shadow imaging with X-rays, pinhole imaging and invertebrate vision)
b. Reflection, absorption, and transmission at interfaces; plane mirrors and virtual images
c. Refraction and Snell's Law
d. Total internal reflection (endoscopes)
e. Dispersion

16. Collecting light to form images

f. Single lenses
g. Human vision
h. Lens combinations (microscopes, corrective lenses)
i. Curved mirrors

Note: Section 6 (waves) can be taught immediately after Section 4 depending on the preference of the instructor.

Section 5. The basis of most biological interactions: electricity and magnetism

17. Electric nature of matter (structure of matter and molecular interactions)

a. Coulomb forces
b. Conservation of charge
c. Microscopic structure of matter, physical process of charging objects
d. Conducting and insulating materials (ionic solutions and hence human body as conductors)

   e. Electric dipoles, polarization, interactions between electrically neutral dipolar objects (molecules as permanent or induced dipoles, hydrogen bonding)

18. Energy transfer through steady currents: electrical circuits

   a. Current
   b. Basic circuit: continuous conducting path for charge carriers
   c. Energy and voltage (gel electrophoresis, nerve networks)
   d. Resistors in circuits (applications of steady state circuits)

19. Electric circuits with time-dependent current

   a. Capacitors in circuits (charged cell membrane is a capacitor; time dependence, nerves and the cable equation)
   b. Dielectrics
   c. Microscopic model of circuits
   d. Electrical safety

20. Interactions at a distance - electric field

   a. Electric field as mediator of electric interactions, force per charge; vector representation of electric fields, field lines; importance of distinguishing source charges from charges acted on by field; connect to defining system; effect of dielectric on electric field
   b. Superposition, electric field of dipoles (heart's electric field as dipole field, electrocardiogram)
   c. Other three benchmark field configurations: sphere, rod, sheet (charge separation across cell membrane modeled as parallel sheets of charge)
   d. Conductors in electric fields (electrical shielding for sensitive electrophysiology measurements; screening of charged macromolecules in ionic solution)
   e. Forces and torques on permanent dipoles in electric fields; polarization of materials in electric fields; effect of dielectrics on electric field (for cell membrane, effect of membrane material on field strength within membrane)

21. Energy and electric potential

a. Electric potential energy (molecular binding energy, effect of dielectric solvent)
b. Electric potential; equipotential surfaces as representation of potential
c. Capacitors as way of storing electric energy (charged cell membrane; medical defibrillator); effect of dielectric constant on stored energy

22. Magnetic interactions and fields

   a. Magnets and magnetic field (magnetotactic bacteria,)
   b. Magnetic force on moving charged particles (mass spectrometers, particle beams, electron imaging, Hall effect) and currents (issues for pacemakers)
   c. Electric currents as magnetic field sources: develop primarily qualitatively/geometrically based on field of wire and field of current loop (electromagnets for MRI)

d. Microscopic basis of particle and material magnetic field sources, spin magnetic moment of atoms/electrons (diagnostic instruments: ESR, NMR)

23. Getting electricity from magnetism

a. Faraday's Law, changing magnetic flux and induced currents and emfs (safety issues for pacemakers)
b. Conceptual motivation for the existence of induced electric fields, unification of electricity and magnetism
c. Conceptual motivation for the existence of copropagating varying electric and magnetic fields (electromagnetic waves) – light
d. Optional: sources of EM waves (antennas)
e. Optional: Polarization of light; circular dichroism, polarization sensitivity in invertebrate vision
f. Optional: Revisit NMR; magnetic resonance imaging

Section 6: Waves

24. Waves: mechanical waves, electromagnetic waves, and wavelike (probabilistic) behavior of matter (understanding both hearing and all kinds of imaging relies on wave behavior)

a. Definitions and representations of waves and related terms: wave speed, amplitude, wavelength, frequency
b. Waves carry energy. Mechanical wave carries mechanical energy (kinetic and potential); electromagnetic wave (photon) carries electromagnetic energy.
c. Wave/particle complementary pictures. Classical wave: energy determined by amplitude; quantum: each particle (material or not) carries certain amount of energy.
d. Waves carry information. Examples of waves exploited by senses: sound as mechanical wave, light as electromagnetic wave.
e. Doppler effect (ultrasound, Doppler velocimetry to measure speed of blood flow)

25. Combining waves

a. superposition: standing waves
b. interference, gratings (X-ray "diffraction"), thin films (Morpho butterfly, AR coatings)
c. diffraction: circular apertures and limits of resolution (microscopy, some eye designs)
d. Combining geometric and diffractive optics: confocal microscopy and superresolution techniques