A stand-alone course in optics, electricity, and magnetism for the life sciences

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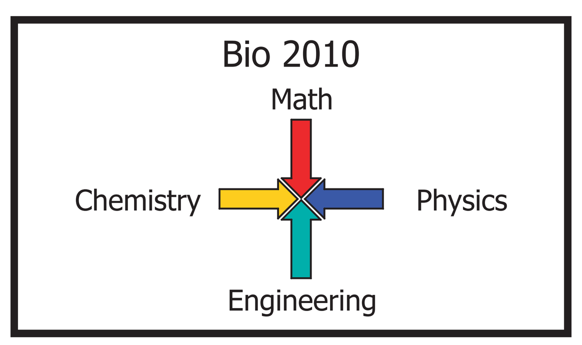
Summary and background

We offer a special life sciences-focused version of the *second* semester of introductory physics, and permit students with reasonable high school physics background to enroll without taking the first semester course.

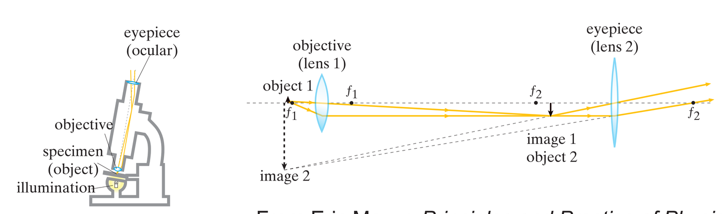
Goals:
to improve the education of life science students
to attract students who presently do not take physics at Swarthmore

Swarthmore previously offered a single two-semester physics course for non-majors, enrolling 60-75 students. Physics is not required for the biology major; many biology majors take no physics, and 10-15 students each year take physics elsewhere in summer school.



The recent National Research Council report, *Bio 2010: Transforming Undergraduate Education for Future Research Biologists*, indicates that strong training in math, physics, chemistry, and engineering is critical for aspiring biologists.

Our biology and biochemistry colleagues identified electricity, electric circuits, and optics (as well as fluids) as the most important topics for their students, with the most applications.



From Eric Mazur, *Principles and Practice of Physics*

To attract students who would not otherwise take physics, our biology colleagues advised us that students should be able to take this course before mechanics.

Syllabus

• Geometric optics, including lens combinations. (2.5 weeks)

• Electrostatics, with extensive discussion of electric dipoles, polarization, and electric fields in dielectrics. Gauss's Law is omitted; electric fields of spheres, lines, and sheets of charge are provided and physically motivated. Field lines are used to motivate electrostatic shielding. (3.5 weeks)

• DC circuits, including electrochemistry of batteries and charging and discharging capacitors (2 weeks).

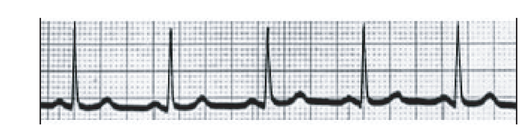
• Magnetostatics, emphasizing current loops as magnetic dipoles, and forces and torques on moving charged particles and magnetic dipoles. Ampere's Law and the Biot-Savart Law are omitted; formulas for the magnetic field of a wire, a current loop, and a solenoid are provided and physically motivated. (2 weeks)

• Induction, including chemical shifts in NMR. (1.5 weeks)

• Electromagnetic waves, including polarization and polarizing optics. (1 week)

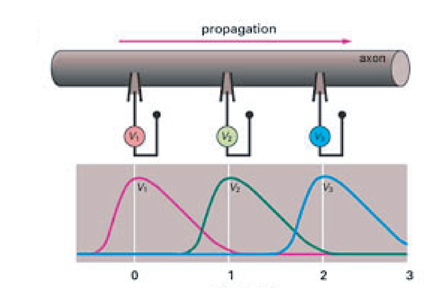
• Interference and diffraction, including X-ray diffraction, limits of resolution, and confocal microscopy. (1.5 weeks)

• Laboratory experiments explore optical microscopy, including immersion lenses, and vision correction. Discuss pinhole vision.


From University of Illinois Medical Center web site

• Discuss gel electrophoresis and effect of dielectric constant of water on chemical reactions and biomolecule conformation. Laboratory includes electrocardiography.

• Discuss cell membrane potentials and neurological action potentials. Laboratory includes measuring RC charge/discharge on an oscilloscope.



From Alberts *et al, Essential Cell Biology*

• Discuss torques on magnetic moments, connect to MRI/NMR and magnetotactic bacteria; discuss nuclear and electronic spin as origin of magnetism.

• Laboratory includes diffraction of different color lasers through circular apertures.

Future additions: improving the electrocardiography lab, incorporating instrumentation from biology and chemistry labs into the laboratory program, and using CCD camera capture and image processing of diffraction patterns.

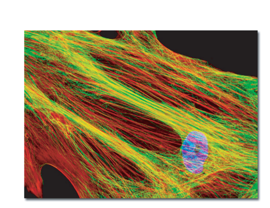
In the future I am considering teaching circuits before electrostatics, to devote more laboratory time to circuits and to introduce students to the more familiar manifestations of electricity before the abstraction of electrostatics.

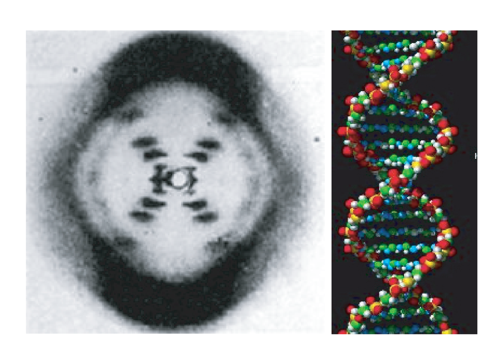
Curricular choices and advantages/disadvantages

Begin with geometric optics:

+ • obvious, appealing applications: highly motivating!
+ • gentler introduction to mathematical problem solving
+ • allows devoting more laboratory time to optics
+ • during optics, offer review sessions outside of class on forces, torques, work, and energy

— • abstraction of electrostatics and use of calculus come as a rude shock


From www.microscopyu.com


Left image: original Franklin diffraction image of DNA. Both images: Kenyon College biology dept. web site.

Double time devoted to both geometric and wave optics

Increase time spent discussing electrostatics in dielectrics

Omit Gauss's Law, Ampere's Law, the Biot-Savart Law, and obtaining electromagnetic waves from Maxwell's equations

+ • frees up time
+ • naturally emphasizes approximations and simplified models
+ • students become very comfortable with field line representations and superposition

— • flux is a new concept when treating induction (used hybrid tutorial to introduce flux as field line density)
— • less total time with electric field (students seemed to rely more on forces, and confuse field and force more)

Allow students to enroll with a strong high school background in mechanics

+ • increases access to course for students going abroad, juggling premed and major requirements

— • extra review of mechanics and waves required outside of class
— • minimizing use of kinematics restricts choices of problems

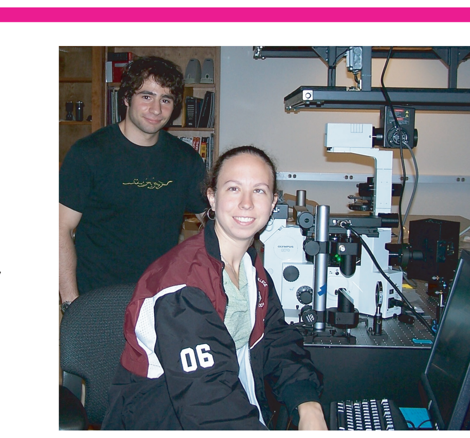
Outcomes (preliminary)

Students were unanimously enthusiastic about the extensive life science applications; several later contacted the instructor, telling her that the material had helped them in biology summer research.

Nine of forty-three students took the sequence out of order (5) or took the first semester elsewhere (4).

Students who took the sequence out of order were strong, highly motivated students and did well in the course. Weaker students who had completed the first semester also participated in the mechanics review sessions.

The primary challenge was accommodating a weaker cohort of students.



"I wanted to tell you how well Physics 4L prepared me for my summer.... All of the [work] we did modeling the cell membrane as a capacitor and the discussions we had about neurons as parallel circuits really prepped for the more complicated things we have been discussing here. Recently we've been calculating currents through mem-brane potassium and sodium channels and accounting for leakage. Just thought you'd like to hear that your class was a success."
—unsolicited student email feedback

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