Integrating biological and biomedical topics into undergraduate physics

AAPM Summer School
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Some statistics for Haverford College

- 1200 student body
- ~10 majors per year (physics + astronomy)
- All majors are required to take sophomore lab + 1 semester advanced lab
- Sophomore lab has one tenure-line, one lab instructor, about 12 students on average
- Advanced lab has one tenure-line professor and about 10 students on average
- 27% of our majors are women (more that that in our classes, due to nearby Bryn Mawr College)
- Our percentage of under-represented groups is identical to national averages

June '09: Scientific Foundations for Future Physicians: AAMC-HHMI "competencies" in physics instead of the current requirement for a year of physics with lab

Competency E3
Demonstrate knowledge of basic physical principles and their applications to the understanding of living systems.

Learning Objectives:

1. Demonstrate understanding of mechanics as applied to human and diagnostic systems.

   Examples:

   - Explain the interrelationships among work, energy, force, and acceleration.
   - Apply knowledge of centripetal acceleration to "g-force" devices used to train jet pilots and astronauts.
   - Explain the mechanical basis for molecular and cellular separation technologies (i.e., centrifugation and chromatography).
   - Apply knowledge of mechanics to movement in biological systems at various scales, from the molecular to the organismal.

2. Demonstrate knowledge of the principles of electricity and magnetism (e.g., charge, current flow, resistance, capacitance, electrical potential, and magnetic fields).

   Examples:

   - Explain how the time to charge or discharge a capacitor depends on the capacitance and the resistance in the charging or discharging circuit.
   - Apply concepts of resistance and capacitance to the electrical properties of myelinated and unmyelinated axons and how those properties affect the travel speed of action potentials in those types of neurons.
   - Apply understanding of electrical principles to the hazards of electrical currents and voltages.
   - Describe how electrical currents establish magnetic fields and how time-varying magnetic fields induce electrical currents in materials, such as metals or biological tissue.

SFFP Challenges for Undergraduate Physics

- Devise courses that helps students meet the report’s competencies
- Sharpen the focus of intro physics for life sciences: not everything in the standard introductory physics course is relevant to life science students
- Work with other STEM colleagues to streamline and focus the pre-health curriculum

AAMC-HHMI Report

- Report implications for physics?
- AAMC message: SFFP offers a way to innovate without previous MCAT/premed requirements as constraints
- Do the right thing—teach what physicians/life science students need to know—don't just teach to MCAT (old or new)
- Opportunities to teach physics majors about bio/med topics

Relevance for you

- Insights into what’s happening at the undergraduate level
- Possible changes in the training of your new students (medical physics and medical students like)
- Opportunities for recruiting into medical physics
- Opportunities for teaching

Life science perspectives

- Bio/Med more quantitative – students need to use (more) physics now
- Skill/knowledge *transfer* physics → biology, isn't working
- Make life science connections with physics in class (not later)
- New content: fluids, basic stat. physics (diffusion, random walks, distributions), electrostatics in media, physical techniques, quantitative methods (data analysis, etc.)

Audience Challenges

- IPLS students don’t understand course goals
- Many feel they “can’t do physics”
- Fixed ideas about “plug-and-chug”
- Learning other approaches in other courses
- “I went into the life sciences to avoid math and physics”
- Diverse student preparation, background
- Diverse student majors, careers

Physics content in SFFP Report

- Most topics sound familiar
- New bio/med emphases
- What physics to omit/de-emphasize?
- Swap engineering → Life science examples

- New curricular materials needed: textbooks, good problems (relevant life science content)

The rub…

Bottom-down approach: teach physics → later see an application ?

"These students see biology in other courses; this is their only chance to learn *physics. Teach foundations, the rest will follow.*"

Top-down approach: Bio problem → motivates physics tools ?

"We know transfer *isn't happe*ning with this approach; teach them what they need to know/use. The extra motivation results in their learning *more physics*."

Less time on…

- Kinematics & friction-free trajectories
- Constant force, acceleration
- Friction
- Hookean mass-spring systems
- Kepler’s Laws
- Gravitation

More time on…

- Actual trajectories
- Acceleration from rest to a constant velocity
- Energy
- Dissipative systems (drag, etc.)
- Thermodynamics at constant T, Pressure
- Elasticity (simple continuum mechanics, fracture, non-Hookean systems)
- Fluids

About the same on…

- Waves & oscillations
- Electricity & magnetism (most)
- Modern / quantum physics

But with attention to applications in life sciences

Physics “process skills”

- Keep physics approach to math modeling
- Simplifying problems, finding essential features
- Quantitative model-building
- Empirical testing, limitations
- Experimental design, critiquing, refinement

How to (better) teach "Process Skills"

- How to harness student's motivation to succeed in our courses?
- Learn about their other courses – connect explicitly to their chosen fields.
- Tell students these skills are a course goal
- Relate to their future career goals
- Test & grade based on these skills

How to (better) teach “Process Skills”

- Know students’ “initial knowledge state”
- Scientific skills develop over the long-term—coordinate with other departments?
- Reference their other science course content? Integrated courses? (integrated sciences @ Princeton? Harvard’s chem/physics intro course?)
- Improve lab & integrate into lecture

Laboratories

- How do we meet the goals of competencies E1 & E2, while including more life science content into the physics laboratory curriculum?
- Many institutions have such labs now—see our wiki website
- New emphases: imaging, diffusion, random walks, medical applications of circuits, optics.
- How to incorporate lessons from physics education research (SCALE UP) to make students learn desired competencies from these experiences?

Intro Lab Examples

- Imaging & bacterial motility (George Washington University)
- Brownian Motion (Centre College, U. Md., Johns Hopkins)
- Fluids & microfluidics (Johns Hopkins)
- Scaling of Bones (Mt. Holyoke & Haverford)
- Optics of the human eye (Pasco)
- ECG lab (Swarthmore)
- DNA crystallography with visible light (Institute for Chemical Education)

Process skills in the lab

- Enhance transfer—show how physics leads into applications (Waves & Sound → ultrasound imaging)
- Hypothesis testing: Bone Scaling → simple Galilean theory does not work!
- Interpretation skills & data analysis
- Teamwork
- Reading (simple, basic) in the scientific literature

Changing gears: how we include life sciences into the physics curriculum

- Introductory physics (labs & course content)
- Sophomore & advanced lab projects
- Statistical physics
- Biological physics / medical physics (dedicated upper-level courses)

Sample upper-level problems

- DNA "zip" model: Modeling helix-coil transitions in biopolymers using 2-state systems (Daune Biophysical Chemistry)
- Modeling why gas transport in the alveoli can take place via diffusion (Benedek & Villars)
- Analyzing RNA polymerase data to show its motion is consistent with diffusion along a DNA molecule
- Explaining why a microfluidics size separation device works

Sample intro problems

- How high can a flea jump using energy stored in its elastin pads?
- What is the distance over which the electric potential of charged DNA molecules decays?
- How does a listeria bacterium achieve its complex trajectories using F=ma?

Resources for biophysics problems in intro & upper-level physics

- ***Physics for the Life Sciences,*** **Timothy McKay (under contract; available in electronic form)**
- ***Physical Biology of the Cell*****, Ron Phillips, Jane Kondev and Julie Theriot, Garland Science 2008.**
- ***Mechanics of the Cell,*** **David Boal, Cambridge University Press, 2002.**
- **Philip Nelson Biological Physics: Energy, Information, Life W. H. Freeman & Co, 2003. (earlier chapters)**
- ***Physics with illustrated examples from medicine and biology*****, George B. Benedek, Felix M.H. Villars, AIP Press, NY 2000: Vol. 1,2 & 3; especially vol.2**
- *Applied Biophysics: A Molecular Approach for Physical Scientists*, Tom A. Waigh, John Wiley & Sons, 2007.
- Glaser, Roland, *Biophysics*, New York : Springer, 2001.
- Cotterill, Rodney, *Biophysics : an introduction*, Chichester ; New York : Wiley, 2002

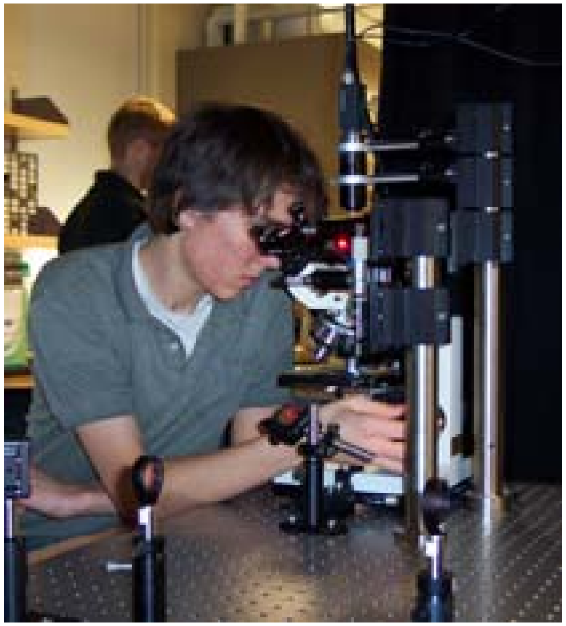
See more at: http://www.haverford.edu/physics-astro/course_materials/phys320/biophysicsCourses.html

Life Sciences & Medical Physics Labs

- We include laboratories on optics of the human eye, ultrasound imaging, sound, ionizing radiation and other topics in our intro and sophomore level physics major lab courses.
- Many of these experiments also make excellent classroom demonstrations
- Our laboratory manuals and classroom demonstrations are designed to emphasize applications to the life sciences (for example, we use a real pacemaker and a teaching (non-operational) defibrillator in our electronics module of electricity & magnetism)
- We also use a model of the inner ear when teaching about sound

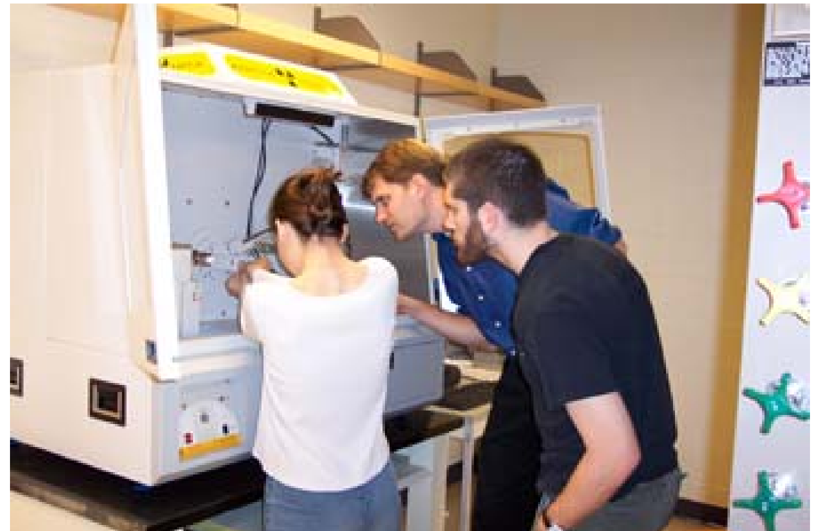
Our present physics lab curriculum

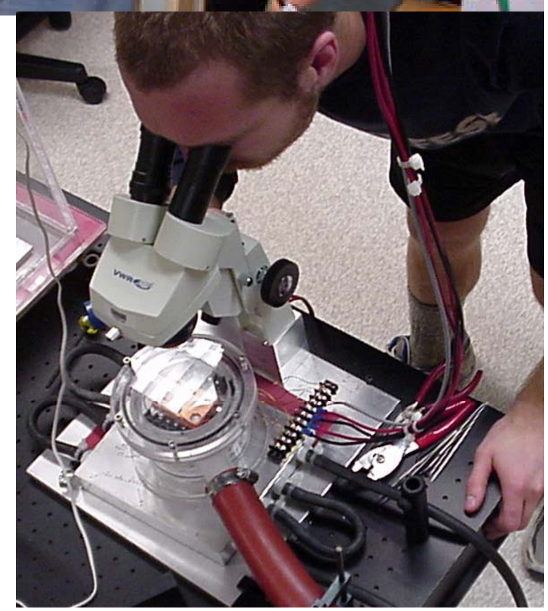
- Intro labs (mechanics, electricity & magnetism, optics, electronics) (two semesters, part of intro sequence)
- Sophomore labs (waves & optics, intermediate electronics, quantum physics) (2 semesters, ½ credit)
- Advanced Labs: Project labs, advanced electronics and computer instrumentation (one semester 1 credit each)
- Plus Observational Astronomy!



Interdisciplinary examples

- Ultrasound Imaging (physics behind medical imaging)
- Laser tweezers
- Quantum dot synthesis and characterization (U. Wisconsin Madison website)
- Microfluidic device fabrication & testing
- Synthesizing carbon nanotubes & imaging them with AFM
- Solid state synthesis of high temperature superconductors, x-ray crystallography, electrical & magnetic properties
- Tomography with Visible Light (based on AJP article)





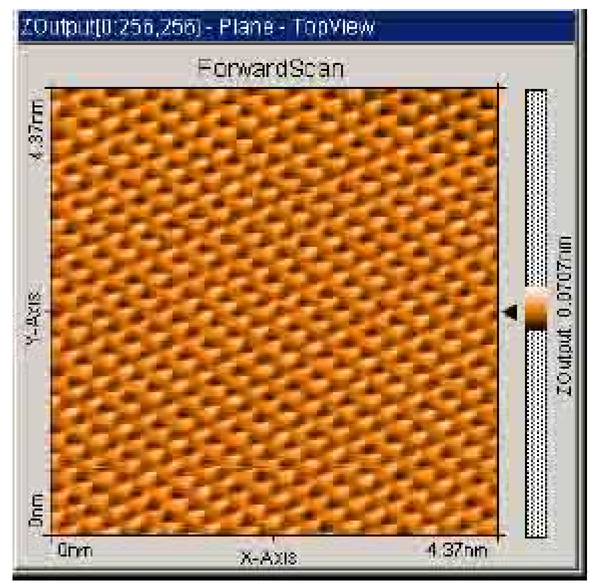
Sophomore Fall Labs

- Electronics, waves & optics
- Electronics (AC circuits, RLC circuits, op-amps)
- Ultrasound imaging
- Geometrical optics & optical instruments (the eye, telescopes, microscopes)
- Torsional oscillator (Teachspin; detailed study of resonance) & normal modes
- Physical optics
- Chaos (Pasco)
- Water wave dispersion

Sophomore Labs--Spring

Quantum Physics

1. STM (Nanosurf EasyScan)
2. Nuclear spectroscopy (with an eye to its use in medicine)
3. Superconductivity & SQUID (Mr. SQUID, Star Cryotronics, Tel-Atomic)
4. Electron Diffraction (with applications to materials)
5. Photoelectric Effect(Pasco)
6. Electron Spin Resonance (Pasco)
7. Laser Mode spectroscopy

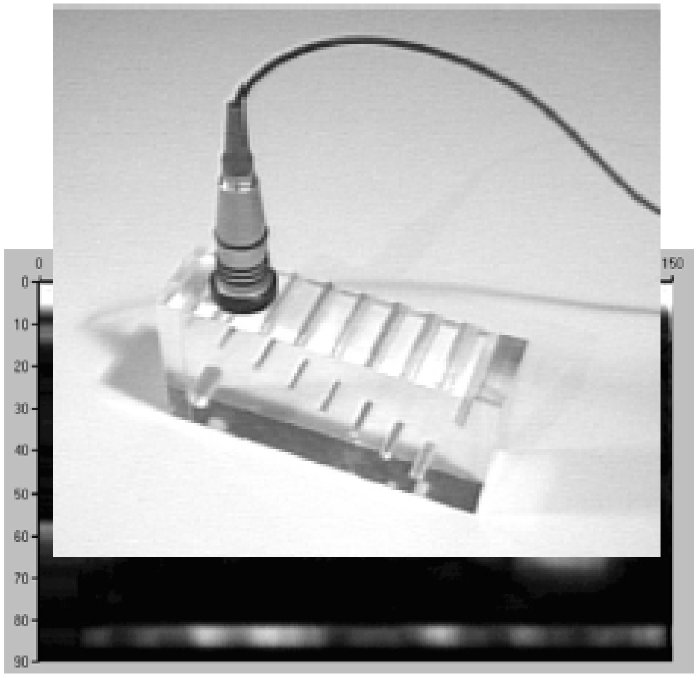


Ultrasound Imaging Physics

- Students use pulse-echo imaging to detect the presence of objects within medical “phantoms” (test samples)
- Both M-mode and B-mode imaging is supported
- The labs explore attenuation, spatial resolution and Time-Gain-Compensation.
- Final project involves imaging a medical model of breast tumors and a kidney “phantom” using an actual scanner
- Doppler and therapeutic units are also available for inexpensive purchase and lab use now
- Images: 3B Scientific & GE

Ultrasound Imaging Physics

- Equipment based on 3B Scientific's actual medical imaging devices
- Lab explores properties of sound transmission, reflection & attenuation, imaging using pulse echoes, time-gain-compensation, resolution



Helpful in putting physics in broader contexts

- How does medical physics influence women's health issues (mammography & breast imaging, obstetrics, etc.)
- Which medical technologies make the most sense in the developing world?
- How is the effectiveness (or safety) of an imaging modetermined?
- …how do we motivate teaching of uncertainty analysis, statistics, estimation, communication skills?

Resources:
Google: "intro physics life sciences" "AAMC-HHMI physics"

- IPLS wiki at https://www.phys.gwu.edu/iplswiki
- AAMC-HHMI report: http://www.aamc.org/newsroom/pressrel/2009/090604.htm
- New MCAT MR5: http://www.aamc.org/students/mcat/mr5/mr5shortoverview.pdf
- My links at: http://www.haverford.edu/physics-astro/Amador/links/