Physics 95 (F17) - Topics in Current Research

Running compilation of course notes for the Fall 2017 Harvard Physics 95 course.

1 Wednesday, August 30

- The objectives of Physics 95 are three fold:
  - Bridge gap between course curriculum and current research frontier
  - Alert students to research opportunities within the department and learn more about grad school
  - Hone written and presentation skills
- A more general goal is to provide students with a feel for the culture, work, and community of physics research.
- Attempt to answer the question: What does it mean when people say they are a physicist?
- Physics is a discipline of science within which there are many sub-disciplines, and it is important to distinguish sub-discipline from the foundational subjects which are the grounding for them.
- **Sub-discipline** are areas of current work or research in physics, while **foundational subjects** are formalisms (containing formalisms, techniques, and concepts) which are applied to study sub-disciplines.
  - Examples of **Foundational subjects**
    - **Classical Mechanics** (*Phys 15A; Phys 16; Phys 151*): is concerned with properties of motion and causes of motion. Serves as the foundation for mechanics of materials or mechanical engineering subjects. Key concepts: equation of motion, Hamilton/Lagrangian Mechanics, Conservation Laws.
    - **Electrodynamics** (*Phys 15B; Phys 232*): studies the creation and properties of electric and magnetic fields from various matter sources. Serves as theoretical foundation for electronics and electrical engineering subjects. Key concepts/results: Maxwell's Equations, Lorentz Force Law, Electromagnetic Radiation.
    - **Quantum Mechanics** (*Phys 143A/B; Phys 251A/B*): the physical properties of systems on the scale of molecules, atoms, or sub-atomic particles. Key concepts/results: Schrödinger Equation, Measurement Problem, Entanglement, QFT[1].
    - **Relativity** (*Phys 15A/16 (latter parts); Phys 210*) includes special relativity and general relativity. Special relativity concerns the implications of the constancy of the speed of light and the imposition that physical laws are the same in all inertial coordinate systems. General Relativity concerns how energy and momentum densities/fluxes curve space time. Key concepts/results: Principles of relativity, Einstein Field Equations, gravitational waves.
    - **Statistical Mechanics** (*Phys 181; Phys 262*): studies the properties of systems with many (i.e., $N \sim 10^{23}$) degrees of freedom. Key concepts/results: Ensemble, Ergodicity, Master Equation. Serves as the microscopic foundation to thermodynamics and includes statistical field theory.

  Throughout most of your undergraduate education you have been learning the foundations which will allow you to begin studying sub-disciplines.

[1] Quantum Field Theory (QFT) is the result of combining quantum mechanics with special relativity

- **Identity through Sub-discipline:** Physicists generally find greater identity in their sub-discipline categorization rather than in their label as ”physicists”. For example, physicists would introduce themselves (to other scientists) by saying they work on ”high energy experiment” or that they are an ”experimental particle physicist”.
- Examples of **Sub-Disciplines**
  - **Biophysics:** using physical principles or experimental techniques, studies biological systems ranging in scale from organismal populations to cells and sub-cellular units.

    Reference: “Physics at Low Reynolds Number” by Purcell [1], *Biological Physics* by Nelson [2]

  - **Cosmology/Astrophysics:** applies physics to systems with length scales on the order of planetary radii or larger. Includes cosmology and astronomy. The experimental work is different from much other work in experimental work in physics in that it is observational.

    Reference: *Chandra: a biography of S. Chandrasekhar* by Wali [3], *Exploring black holes: Introduction to general relativity* by Taylor and Wheeler [4]

  - **High Energy Physics (HEP)/Particle Physics:** study of physics on the smallest length scales and often at the highest energy scales. Experimental work is done at large colliders/accelerators around the world. Not all experimental particle physics is studied at high-energy.

    - **String Theory:** Included in HEP theory, although it is argued that the field has more in common with mathematical fields than historical (or current) fields of physics

    Reference: *Warped Passages* by Randall [5], *QFT in a Nutshell* by Zee [6]

  - **Nuclear Physics:** studies states of matter and processes defined by the strong nuclear force. Has considerable cross-over with HEP. The experimental part of the field is developing into the “big science” which typifies high energy experiments.

    Reference: *Introduction to Elementary Particles* by Griffiths [7], *Introduction to Nuclear Physics* by Krane [8]

  - **Public Policy:** governmental work which determines how science is funded and more generally regulated within the country. This work may not concern physics proper, but the government often employs physicists to do it.

    Reference: Suggestions welcome

  - **Computational Physics:** applies numerical, programming, and algorithmic methods to solve physics problems, or develops new methods grounded in existing computing infrastructure.

    Reference: *Computational Physics: Problem Solving with Python* by R. Landau, Páez, Bordeianu [9]

  - **Atomic, Molecular, Optical (AMO) Physics:** applies quantum mechanics to study atoms and molecules in isolation or how each interact with light in various systems. Work with Bose-Einstein condensation falls into this area.

Reference: Suggestions welcome

- **Condensed Matter (CM) Physics** (Squishy (i.e., soft CM) and $\hbar$ (i.e., hard CM)): the study of any type of matter which is not in a gaseous phase. Includes, typical states like liquids as solids, but also nuclear matter like the quark gluon plasma and superconducting matter.

  Reference: "More is Different" by Anderson [10], *QFT in a Nutshell* by Zee [6], *Soft Condensed Matter* by Jones [11], *Condensed Matter Field Theory* by Atland and Simons [12].

- **Quantum Computing:** the implications and the construction possibilities of computation in the quantum regime. Extends from and can overlap with AMO physics.

  Reference: "Quantum information and computation", by Bennet and DiVicenzo [13], "Undergraduate computational physics projects on quantum computing" by D. Candela [14]

- **Fluid Dynamics:** studies the physical properties which govern the evolution of systems which can be characterized as fluids. Typically not taught in the undergraduate physics curriculum.

  Reference: *Fluid Mechanics* by Landau [15]

- **Geophysics:** Study of the physical properties and processes of the earth. A field as multifarious as biophysics.

  Reference: Suggestions welcome

- $ **Physics/Quantitative Finance:** develops stochastic models of the stock market to predict/study the value of stocks and various other financial instruments. Arguably an area of applied mathematics, but firms where work was done previously employed physicists because of their quantitative modeling skills.

  Reference: *My Life as a Quant* by Derman [16], *The Physics of Wall Street* by Weatherall [17]

- **Sub-disciplines not mentioned:** History of Physics/Philosophy of Physics (e.g., *The Structure of Scientific Revolutions* [18]), Plasma Physics, Photonics.

- **Theorists and Experimentalists:** Ever since the middle of the 20th century, the knowledge and skills necessary to do physics research have become so specialized that the physics community has effectively divided into two cultures: theorists and experimentalists.
  - In general, theorists develop theoretical models of nature, and experimentalists test these models. Physics needs both to progress.
    - **Theorist examples:** Helen Quinn, Steven Weinberg, Subrahmanyan Chandrasekhar
    - **Experimentalist example:** I.I. Rabi, Chien-Shiung Wu, Edwin Hubble
  - Even if scientists sometimes change sub-disciplines, they often continue to work as experimentalists or theorists in their new discipline. The most historically famous counter example is Enrico Fermi.
  - **Educational Bias:** Your education up to this point has been largely biased toward training you to become and evaluating you according to the standards of theorists. Even experimental physics courses don't teach the full spectrum of skills needed to become an able experimentalist. To

obtain exposure to experimental physics, it's best to work under an experimentalist in a summer or semester research project.

  - **Why does education focus on theory?:**
    - **Cost and Facility:** Theory-based courses are cheaper and easier to administer since they require less equipment.
    - **Common Language:** Having early physics education focus on theory gives physicists a common language and intellectual framework through which new ideas could be understood by referencing a core of widely accepted ideas and theories.
  - **Developing Experimental Skills:** Given that traditional educational metrics are not geared to evaluating experimental ability, how do you develop experimental skill?
    - **Skills of an experimental physicist:**
      - Electronics: circuit design and analysis *(Harvard Physics E-123a/-E-123b: Laboratory Electronics Analog/Digital Circuit Design)*
      - Machining: manufacturing experimental parts (Harvard Physics/SEAS Machine Shop page)
      - Computing: programming, statistical analysis, simulation *(Harvard CS50: Introduction to Computer Science; Harvard CS109: Introduction to Data Science)*

      and sub-discipline specific experience These skills are not probed in your standard physics curriculum. You get to practice some of them in Harvard Phys 191r.
    - **Demonstrating mastery?** In general, it is difficult to demonstrate mastery in all of these directions when you're an undergraduate. It is more likely to be proficient in one direction and to then use this proficiency to obtain an assistant position in a research lab.

- **Technical Communication:** Crucial to being a good scientist is not only doing good work but communicating that work to others. The course will provide practice in this direction in various ways.
  - **Evaluating a Talk:** When listening to a talk during the department colloquium, or at any other time during your undergraduate career. Ask:
    1. Can I talk to this person about their work?
    2. Are the tools and methods they're discussing interesting?
    3. Is this an effective talk?

    These questions can help you determine good people to contact for future research queries.

- **Homework (Details on Course Website):** Watch presentation on creating effective slides, and create a single slide explaining whether a reporter should worry about a spy satellite.

2 September 11, 2017

- By reviewing the submissions to the single-slide assignment, we will outline the important aspects of conveying information to a non-technical audience.
  - **Relation to longer talks?:** Multiple-slide talks are a compilation of single slide talks, so the principles for executing this assignment can be applied more generally.
- **Importance of Technical Communication:** Even as an established researcher, giving presentations (rather than writing papers) is the dominant mode of technical communication.
  - **Technical papers are hardly read:** (Stackexchange: How many people read an individual journal article?) Estimates of how many people read one's work are unclear, but, as compared to papers, presentations are certainly a faster mode of conveying the essence of your work to large numbers of people.

- **So should scientists still write technical papers?** Yes! ("No one reads your paper either" by Claus Wilke)

- **The bane of PowerPoint:** PowerPoint (or Keynote) is not going away. But, many slide presentations are poorly prepared because students and professionals aren't trained in delivering or preparing good power points.
  - "Death by Power Point" by Alexei Kapterev
  - "How to avoid death By PowerPoint" | David JP Phillips | TEDxStockholmSalon

- You can easily distinguish yourself by preparing power points which are slightly better than average. Some rules of thumb
  - **Don't assume a large amount of retention:** Unless they have a question about a slide, readers often forget the details of your slide after you move on from it.
  - **Think about Message, Clarity, and Audience:**
    - **Message:** What is the main message I am trying to convey? Put this message early on in this talk and put it again at the end.
    - **Best way to convey:** How best can I convey this message as clearly and as accurately as possible?
    - **Audience:** What is the right way to convey this message to my particular audience? What assumptions can I make about their background?
      - *Example:* When you state that something is a "vector" without context you should make your audience is composed of a group of people who would know exactly what you mean. To biologists a vector is something used to transfer genetic material; to mathematicians a vector is a point in $\mathbb{R}^n$; to computer scientists a vector is a sequence container; to physicists a vector is a physical quantity with direction and magnitude.
  - **Title space:** Don't waste title space with throw-away words. Use the space to write the question the slide answers or the answer for the question the slide sets up.
  - **Blocks of Text:** They are intimidating and require too much involvement from the audience. Save the blocks of text for papers.
  - **Convey Qualitatively:** Conveying a complex idea through a figure or an analogy is a good idea so long as you remain faithful to the complex idea, or explain how the analogy is different from the realistic case.
    - *Good Example:* Using the blurriness of reading the digits of a credit card to explain angular resolution.
    - *Not so good example:* Using a rubber sheet to explain the curvature of space time (unless you emphasize that the sheet is two-dimensional and space like and spacetime is not).
  - **Should you include mathematics or calculations?**
    - **Americans, Math, and The Metric:** Americans are generally afraid of math (perhaps because they're bad at it?[2]) and do not think in metric units[3], so including many equations with discussions of kilograms and centimeters may confuse and annoy your audience (assuming you aren't speaking to people in a quantitative field of work).
    - **Equations for Non-Scientists:** In general, equations are only manifestly meaningful to people who constantly think through equations. Non-scientist audiences should not only be given equations and numbers, but should also be given a context to make the equations/numbers meaningful.

[2] "Americans are spectacularly bad at answering even the most basic math questions", *Quartz*

[3] These two tendencies which are perhaps related. (The United States and the Metric System, NIST)

    - **Style of Explanation:** Both of the above points are pushing against our propensity to explain things the way we understand them. The speaker should always think about the explanation his audience will likely understand/accept.
  - **Flip-side of Math Phobia:** The flip-side of math-phobia is that audiences are often willing to grant intellectual credibility to those who justify their work through equations. Without agreeing with the legitimacy of such granting, we can say that placing mathematics in a presentation (if only for "shock and awe" purposes) can sometimes contribute to your ethos as a speaker/presenter.
  - **Technical Glitches:** As you're giving presentations in various universities or conference spaces, it is likely that something unrelated to the content of your presentation will go wrong.

    To prevent compatibility or animation problems:
    - PDF is the standard format for talks and it is compatible with all computers with a PDF viewer. (Make sure to include each build as a separate slide if you're converting between formats)
    - Have multiple versions of your talk in Keynote, PowerPoint, or PDF. *Caveat:* This is possible difficult since animations don't translate well (or at all) to PDF.
    - Try to test your presentation on the in the talk venue before you give your talk.
  - **Grammar and Spelling:** Having spelling mistakes or even non-standard syntax/grammar styles undermines or distracts from your presentation. So proofread the sentences in your presentation.
    - **Non-Native Speakers:** Have a native-english speaker review the grammar or spelling in your work.
  - **Slides often Stand Alone:** Your slides are generally not only experienced with your voice over. If you give a good talk, you should expect that people will request your slides.
  - **Modulating information density is a balancing act**

    Put too much text on your slides, and you're committing one of the common mistakes of slide presentations. Not enough text, and your slides are not understandable without your commentary. Finding the best way to present information so that it is meaningful in the moment and still useful afterwards involves a delicate balance between clarity and aesthetics.
    - **Use pictures/diagrams and labels:** Images are informationally dense and easier to assimilate than paragraphs provided they are well labeled and documented.
    - **After "The End":** After you create the main slides of your talk, include slides at the end which respond to potential audience questions
  - **Constraints of Space and Time:** Whenever you give a slide presentation you are constrained by the size of a single slide and by the amount of time you will have to give the presentation. Far from being limiting, these constraints should be seen as opportunities to determine the essential message of your research and the best ways to convey it to an audience.
    - Auxiliary issues: Think about the size of the screen and the lighting in the room. Make sure your text would be legible for

- **Candid statement about theory talks:** Initial audience questions often act as probes to see how well speaker understands his or her subject. Failing to answer these initial questions correctly (or at least carefully) can reduce your credibility in the audience's eyes and turn them into a "rabid pack of dogs" who keep asking vaguely antagonistic questions throughout your talk.

  Ways to deal:
  - Prior To Talk: Make sure you have asked yourself the basic questions about your research problem.
  - If questions become too persistent: "Pick out alpha dog and wack him over the head with a bat"; i.e., answer the question of one of the senior researchers carefully and with attention to detail.

- If questions become too persistent #2: say variant of "Excellent Question! Let's discuss it after the talk!"
- If questions are tangential or time consuming: say variant of "I'd like to focus on the core of the problem for the remaining parts of the talk," or "I'm going to discuss the remaining slides in full, and I will happily answer any questions you have after the talk."

Do NOT try to bullshit your way out of these initial questions. Your audience will often realize when you're putting up a smokescreen because you do not want to admit you're ignorant of something.

- Instead, admit when you don't know something and be available to discuss the question with the asker after your talk.

- **Job Talks:** The purpose is to assess your ability to communicate a technical topic in a meaningful way. This means you shouldn't just try to prove that you're the smartest person in the room, but should rather try to convey something meaningful
  - Bonus points if you are sufficiently knowledgeable about the research of the institution you're presenting in that you can make well-informed connections between your work and the work of your potential colleagues.
- **Homework (Details on Course Website):** None! Come to class on time for Lab Tours.

3 September 18, 2017

- Professor Doyle and Professor Samuel Lab Tours
- **Homework (Details on Course Website):** Create an elevator pitch on a topic from the provided list or an approved topic of your choice.

4 September 25, 2017

- We are practicing how to have brief but high impact conversations. These conversations are often unplanned, but they can have a major effect on your life and subsequent work.
- Points to remember for Elevator Pitches (or for general informal but purposeful introductions)
  - **Hello:** State who you are according to your sense of what qualities are important to your message. Are you a denizen of San Francisco who is interested in the problem of gentrification? A undergraduate researcher interested in improving computing resources for the college population?
  - **Content:** State what you want to communicate. Try to present a narrative focused around one or two main points, rather than a list of statements.

    You can begin generally and abstractly, but your content should eventually evolve toward something that is concrete and is actionable for your audience.
  - **Follow-Up:** State how you will follow up with the person. Did this first conversation go so well that you can meet them for lunch? Or is it more appropriate to ask for an email address and continue the conversation online?

- **Clarity of Objective:** Throughout the pitch, be clear bout your objective. Are you just trying to communicate to a potential colleague? Do you want a job? A reference? A promotion? Your objective defines what information you include in the pitch and how you frame the follow-up.

- **Competing Values:** It's important to recognize the values of person to whom you're talking or to at least recognize that he or she does not necessarily share your values. If you do know their values, it is better to try to make contact with those values rather than to try to impose your own on the conversation.
- **Best Laid Plans:** It is important to plan what you will say, but remember you are having a conversation not giving a monologue. You will likely be interrupted and derailed by questions, so don't allow your delivery to be so practiced as to be inflexible.
- **Vagaries of Evidence:** You should be in complete command of the relevant facts. Having a few pieces of empirical data is useful (also worthwhile to be familiar with the sources of these data).
  - **Incentives over Evidence:** Recognize as well that few people are swayed by evidence alone. Rather most people reason ideologically and then rationalize adopting or ignoring evidence so that their ideologies remain intact. ("The Meaning of Scientific Truth" by D. Kahan)
- **Homework (Details on Course Website):** Models, Physics, and Life Science Assignment

5 October 2, 2017

- What characterizes/distinguishes research in physics?
  - **Reducing (Reductionism):** Studying physical systems by studying the fundamental interactions of the system; Leads to an "inward bound" [19] perspective on physics where the community seeks to develop physics on smaller and smaller distance scales.
    - **More is Different:** [10] One of the insights of post 1950s physics is that the reductionist approach does not always provide the most important details of a system. Understanding the fundamental properties of a single particle does not allow you to predict what happens when there are $N \gg 1$ particles. In other words

$$\text{Whole} > \sum(\text{Parts}) \tag{1}$$

  - **Abstracting:** Taking a physical system and removing all details which are not seemingly relevant to the focal question. This is what is typically characterized as "Thinking Like a Physicist"
  - **Assumption Clarifying :** Being specific about what you're neglecting and including in your abstracted system
  - **Building Knowledge:** involves a slowly growing edifice of knowledge like the construction of a building. There is an answer to the question of "Why?" for most physical processes, and this answer is often connected to the principles of physics.
  - **Quantitative and Mathematical:** Using formalisms and techniques in mathematics to answer questions about the physical world
    - **Mathematical Modeling in and out of Physics:** Physics is not the only field of knowledge that uses mathematics, but mathematical modeling in physics is distinguished from modeling in other fields in that physics models are
      - Grounded in physical principles
      - Represent the constitutive reality of modeled system.

      As an example of the latter point, in general relativity $g_{\mu\nu}(x)$ does not merely *model* spacetime; it *is our most precise definition* of spacetime. But in economics, while a function $p(t)$ can model the price of a product, it does not define the product.

- **Falsifiable:** Developing predictions which can be compared with observations and are thus falsifiable. This is how Karl Popper [20] defined a valid scientific theory; Popper also claimed that the theories most consistent with predictions are the ones eventually accepted.
  - **Physicists against String Theory:** About a decade ago (and even still today), the common criticism levied against string theory was that it was not falsifiable and hence was more mathematics than science [21] [22]. Some string theorists rebutted that it takes time develop the apparatus to test novel theories.
  - **Kuhn against Popper:** Thomas Kuhn [18] (who studied physics and later the history of science at Harvard) disagreed with Popper saying that theories are not accepted according to an objective accounting of number of falsifications, but subjective value systems defined by communities of scientists.
- **Empirical:** Studying the physical world through senses or experimental observations.

- **Physics Envy:** The "Physics Approach" is not all powerful. Often scientists run into problems when they try to apply this approach to non-physical systems, such as economies. (See Physics Envy, Also see this hilarious spoof of the traditional concept.)

- **Why do we model?**

  In physics the main purpose of models is to predict something which can be compared with experiment, but outside of physics mathematical modeling cannot always be used to cleanly predict outcomes.

  The following is taken from "Why Model?" by J. Epstein.

  - **Explain:** this distinct from predict, e.g., cosmology explains origin of universe, but since it concerns something from the past, it does not predict the results of an experiment; evolution explains the diversity of organisms, but (in its original incarnation around the late 19th century) did not predict anything about organism.
  - **Guide Data Collection:** Any attempt at data collection relies on some model of what variables depend on one another.
  - **Suggest analogies:** Different systems with similar mathematics can have analogous relationships. For example, black holes and thermodynamics are governed by mathematically similar laws; random walks can be used to describe a diffusing particle or price changes of a stock.
  - **Discover new questions:** Attempts to understand a model can lead to new questions about the system of study.
  - **Promote a scientific habit of mind:** Creating explicit models forces us to be precise about what we do or do not know about a system.
  - **Demonstrate tradeoffs:** Models provide a way to consider contingencies, i.e. if X happens then we have Y, but if X' happens then we have Y'.
  - **Expose the prevailing wisdom to be incompatible with data:** For example, the calculation of the cosmological constant using quantum field theory revealed that quantum field theory extrapolated to a cosmological scale was incomplete.
  - **Train practitioners:** Models provide simple scenarios in which scientists in training can apply the concepts they are learning. For example, spring systems teach scientists about oscillations; the Bohr model of atom teaches scientists about quantum transitions.

- **Wrong but Useful:** Important to remember the dictum: "All models are wrong but some are useful."

- **About Biology:** Biology is not necessarily amenable to the physics approach because biology concerns complicated, messy systems whose properties cannot always be reduced to a few universal (mathematically expressible) principles.

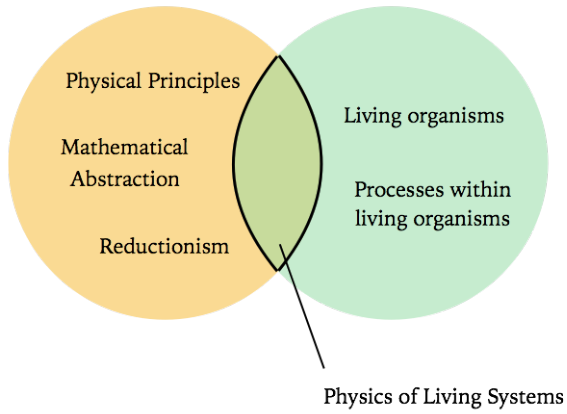

Figure 1: What characterizes Biophysics? The above is a *theoretical* physicist's depiction of biophysics.

- William Bialek [23] : "While physics is defined by a unity of approach, biology is defined by a unity of subject matter." All areas of physics make use of the following above listed approaches, but all areas of biology are concerned with the study of life or life-related processes. Biophysics attempts to find the cross over.
- **Theory isn't everything:** There have been many scientists who started in experimental physics and moved on to molecular biology
  - Maurice Wilkins and Francis Crick who assisted in the discovery of DNA
  - Xiaowei Zhuang a Professor of Physics, Chemistry and Chemical Biology here at Harvard

- **Pro Argument:**
  - **Reductionism:** A reductionist model of science is useful when you have a lot of data
  - **Physical Principles:** Using physical principles allows you to access bigger picture results
  - **Modeling:** Models give insights and allow you to search a smaller solution space; allows for computational techniques
  - **Testable Predictions:** Mathematical models provide testable predictions of reality
  - **Assists Experiments:** Helpful to go along with experiments: Allows one to investigate black box issues. It is impossible to do experiment without at least some causative or correlative model of what is happening in what you're studying. Making such models mathematical makes them more precise in their definition and predictions
  - **Fail-Proof:** Having a mathematical model and making predictions from it is always useful because you still learn something even if your prediction is wrong.

- **Cons - Part I:**
  - **Education:** Difficult to communicate work to other biologists. Biologists are trained through experiments not model building.
  - **Spherical Cow Problem:** Oversimplification through modeling makes models irrelevant.
  - **Tyranny of Equations:** Not every important result or idea in science can be reduced to an equal sign. For example, the central dogma of molecular biology (DNA$\rightarrow$ RNA $\rightarrow$ Protein) has no equal sign.
  - **Statistics is Not Enough:** Models can be developed but attempts to fit to data can lead to fine-tuning and over fitting.

- **Cons - Part II:**
  - **We are being imprecise:** We are conflating models, mathematical modeling, and physics, but they are not all the same.
    - **Model:** (*Stanford Encyclopedia of Philosophy*) "Model's are a representation of a selected part of the world." Thus maps can be models (e.g., MBTA subway system), diagrams can be models (e.g., double helix model of DNA), and so can equations (e.g., the Standard Model of Particle Physics).
    - **Mathematical Model:** A mathematical representation of a selected aspect of the world. Examples: $dN/dt = rN(1 - N/K)$ describing bacterial growth; binomial distribution for steps in a random walk; linear equation describing relationship between high school grades and college grades.
    - **Physics Model:** A mathematical model which is grounded in the principles of physics. By this definition all physical models are mathematical models, but not all mathematical models are physical models. A differential equation describing bacterial is a mathematical model but not a physical one.

  It is clear that models and mathematical modeling are useful in biology.

  What is less clear is whether the physicist's tendency toward reductionism, abstraction, and universal principles is useful to biologists.

- **Interrogating the discussion itself:** Student quote: "Should we even be having this pro- and con- discussion? Bialek is wrong. What defines a scientific discipline (including physics) is the questions the discipline seeks to answer and not the approach someone takes in studying the discipline."
  - **Question Remains:** ... so would the *questions* a physicist might ask about a living system be of interest to someone who is trained as a biologist?
    - **Former Harvard Undergrad:** A recent famous example of a physicist asking questions about living system is "The Statistical Physics of Self-Replication" [24] written by a former Harvard undergraduate.
  - **Is this a moot point?** Perhaps the point is still moot. Student quote: "Physics and biology are artificial (and mostly sociologically defined) divisions of the natural world, and scientists should instead focus on the questions they are trying to answer and not the categories in which these answers fall."

    > **The Map and the Territory:** From a philosophical perspective this sounds nice: Just do good science, and what you discover would be useful no matter how it is categorized. More pragmatically, funding requires some categorization, and all scientists work with an implicit (often disciplined defined) mindset which constrains how they do research. This categorization/mindset has been argued to be key to the rapid progress of science [**?**].
    >
    > Unattributed quote: "The lines of the map have no bearing on the nature of a territory but it is only through such lines that the territory could ever be understood."

- **Homework (Details on Course Website):** Choose presentation topics for technical and public talks for the coming weeks.

6 Monday, October 9

- Columbus Day Holiday

7 Monday, October 16

Group A: Technical Presentations

- **Tsunamis** (by Aaron Argyres): the physics of tsunamis; the dispersion relation for shallow water gravity waves; categorizing tsunamis as shallow water waves; what happens when the wave reaches the shore (shoaling)
- **Exploring the kinetics of sRNA through machine learning techniques** (by Carlo Bocconcelli): sRNA as a non-coding RNA molecule for gene-expression; the kinetics of sRNA binding; goal is to determine how mutations change the binding kinetics of sRNA; definition of neural nets; how to vectorize sRNA
- **Cosmic muon background at the LHC** (by Madeline Bernstein): ATLAS collaboration at the LHC; structure of the detector; coordinate system of experiments; definition of displaced vertex in particle collisions; displaced vertex searches for SUSY processes; which cuts to use to select appropriate range of data; characteristics of two-muon events; how to search for single-muon events
- **Making monolayers of colloidal particles** (by Zachary Chambers): definition of a monolayer as a ~ 10 nanometer suspension of particles; monolayers can be used to make janus particles (spherical nanoparticles whose surfaces are made of two different materials); process of making monolayers through evaporation; "coffee ring" effect; the effect of flow fields
- **Inertial confinement fusion** (by Liam Corrigan): process of nuclear fusion; the relevance of quantum tunneling; requires 10^4 eV for process to occur; density (n) and time-in-fused state (τ) constraints for success ($n\tau > 2 \times 10^{20}$ s/m^3); inertial confinement seeks to maximize density of pellet; use of a hohlraum; difficult to achieve fusion due to energy loss during process
- **Raytracing for the Advanced Particle-Astrophysics telescope** (by Sòley Hyman): motivation stems from gravitational wave and dark matter research; general design of telescope (scintillating fibers, wavelength shifting fibers, cesium iodide, photomultiplier tubes); description of small-scale prototype; simulating fiber geometry to maximize light output; Raysect package in python; round fibers as the apparent optimal fiber geometry
- **Low dimensional materials** (by Brian Marinelli): graphene, hexagonal boron nitride, and niobium diselenide as example materials; creating quantum heterostructures; layering and fabrications; explanation and relevance of superconductivity; Andreev reflections; environment for testing (low temperatures and tunable magnetic field); relationship between superconducting gap and Andreev reflection.

8 Monday, October 23

Group B: Technical Presentations

- **Analyzing Simulated Galaxies** (by Bryan Brzycki): definition of a galaxy; structure and properties of a spiral galaxy (disk, bulge, and halo); defining the circumgalactic medium (CGM); simulating galaxies; precipitation in galaxy gas simulations; star formation rate in simulations and in reality are different; ways to correct simulation
- **Quantum Scarring** (by Davis Lazowski): unstable periodic orbits of a classical system lead to enhanced probability density of orbits in corresponding quantum system; 2D stadium billiard system; the effect of perturbations on the scars; Lukko scars as "scar-like" regions in trajectory space that appear in the presence of perturbations; adding randomness and gaining order; open questions

- **Moral Condemnation** (by Parth Mehta): why would people react more strongly to chemical weapons than to bombs, or, why do we condemn what we condemn? logic and reason?; higher order beliefs; game theoretic model suggests categorical metrics have a structure of incentives which make condemnation more possible relative to continuous metrics
- **Boston School Choice Mechanism** (by Dionisie Nipomici): what is the best way to match students with their desired schools?; how current matching algorithm works; problems with current process; deferred acceptance algorithm
- **Measurement of a First-Order Liquid-Liquid Phase Transition to Metallic Hydrogen** (by Hanl Park): Wigner-Huntington model for atomic metallic hydrogen; proposed properties of metallic hydrogen; predicted liquid-liquid plasma phase transition; pathway I transition is driven by diamond anvil pressure and results in solid metallic hydrogen; pathway II transition is driven by laser heating and results in liquid metallic hydrogen; for pathway II, how to laser heat surface in order to continuously collect data points; how to confirm existence of first-order phase transition; additional data collected recently
- **Protein corona pattern recognition for noninvasive coronary artery disease diagnosis** (by Gha Young Lee) the utility of nanomedicine; nanoparticles surround proteins forming "protein corona"; using protein coronas as disease signatures for coronary artery disease; sensor array to detect organic compounds; using PCA to quantitatively define signatures
- **Scalable signal region identification with applications to the ATLAS WWW analysis** (by Jonah Philion): discovery of the higgs boson; doubly charmed baryon discovery; sigma and significance; production of three W bosons; using machine learning to select events for the observation of the process
- **Post-processing vibration removal for STM** (by Bryce Primavera): basics of scanning tunneling microscope; preserving sensitivity of tip requires extensive effort (e.g., acoustic foam, floating on air springs, deep underground) to isolate measurements; transfer function and vibration propagation; scheme for cancelling noise

9 Monday, October 30

Group A: Public Talks

- **Ethical Considerations in CRISPR/Cas9 System Use**(by Aaron Argyres): mechanism of CRISPR/Cas9 gene editing; governing principles of gene editing; possibilities of unintended mutations in the procedure; non-therapeutic treatments (enhancing athletic or intellectual abilities); variations in access to treatment; gene editing tourism
- **Space Junk—How do we clean Earth's Orbit?** (by Carlo Bocconcelli): various orbital radii around earth are used for unique purposes; satellites are used for communication, weather, "general" government usage; there are 100 billion dollars of technology which are at risk due to other orbital objects; description of Kessler effect; reason for low barrier of entry into space; how we develop better detection and disposal of satellites; the way increased regulation can prevent catastrophic failures
- **The Observation of Gravitational Waves** (by Madeline Bernstein): Einstein and General Relativity; massive objects moving in space and gravitational waves; how we detect gravitational waves; laser beams and interference patterns; the role of the LIGO experiment; Sept 14, 2015 measurement of gravitational waves from black hole merger
- **Molecular Machines** (by Zachary Chambers): definition of a machine; definition of a molecular machine; chemical versus mechanical interactions of molecules; development of the rotaxane and molecular elevator; creating energy inputs and outputs; future of molecular machines

- **The Cosmic Microwave Background: What is it, and why do we care?** (by Liam Corrigan): formation of the CMB in the history of the universe; anisotropies (i.e., angular distribution of differences in temperature) in the CMB; the physical implications of the existence of the CMB; current research and using CMB to find evidence of primordial gravitational waves and inflation
- **The COHERENT Experiment: A Portable Neutrino Detector** (by Sòley Hyman): this year's (i.e., 2017's) discovery of the coherent neutrino-nucleus elastic scattering; neutrinos in particle physics; flavors, oscillations, and detection of neutrinos; typical neutrino experiments are massive (e.g., IceCube experiment is many times larger than Eiffel Tower) and expensive; basics of the coherent neutrino-nucleus scattering; COHERENT detector is the size of a milk jug and is cheap; materials used in the detector; first time interaction was detected since its prediction 40 years ago; implications for dark matter searches and studying nuclear reactors
- **Maintaining the U.S. Strategic Petroleum Reserve** (by Brian Marinelli): the Strategic Petroleum Reserve (SPR) as the largest emergency oil supply; location in Gulf Coast states; original purpose as a means of protecting against oil supply shocks; current efforts to phase out SPR; why the U.S. still needs the SPR

10 Monday, November 6

Group B: Public Talks

- **Solving the Missing Baryon Problem** (by Bryan Brzycki): baryons are neutrons and protons and constitute normal matter; energy and matter composition of the universe; "weighing" the universe through sky surveys and the Cosmic Microwave Background (CMB); 10% baryonic matter is in galaxies and clusters; 60% is in the intergalactic medium; the missing 30% of matter could be in filaments connecting galaxies; Sunyaev-Zeldovich effect; detection strategy is to use the CMB to identify the filaments; the detection of filamentary gas shows good correspondence with 30% estimate
- **Why funding a better ocean-floor survey will save lives** (by Davis Lazowski): limits to staying safe from tsunami's is preparation and early-warning systems; since the development of early warning systems, the number of tsunami deaths in Japan have decreased from pre-1960 years; it is difficult to prepare for freak waves because they are difficult to predict; example of freak wave after 2011 Great East Japan earthquake; studies of branched flow have improved understanding of freak waves; better knowledge of ocean floor improves calculations of how branched flow affects freak waves
- **Machine Learning** (by Parth Mehta): Predicting the IMDB score for a movie from its reviews; applications of machine learning to spam filtering, stock market prediction, and generating storybooks; neural nets; how to model nature; hidden layers in neural nets; back propagation in neural nets; machine learning uncovers generalizable patterns
- **Gravitational Waves–detection from colliding neutron stars!** (by Dionisie Nipomici): September 2015 and August 2017 detections of gravitational waves; interference patterns and interferometer; recent detection represents the first detection of gravitational waves with their electromagnetic wave counterpart; searching for the source of the signals; background on neutron stars; heavy elements and neutron stars; future questions concerning star explosions, dark matter, expansion of universe
- **Once Theory, Now Reality: Solid Metallic Hydrogen** (by Hanl Park): history and properties of solid metallic hydrogen (SMH); superconducting and superfluid properties of SMH; electronics and rocketry usages of SMH; was it actually discovered? (reasons why and why not); production tests and scaling; verifying metastability and superconducivity

- **2017 Nobel Prize: Cryo-Electron Microscopy** (by Gha Young Lee): basic physics of microscopy; how X-ray crystallography works; how electron microscopy works; flaws with X-ray crystallography and electron microscopy (necessity of perfect crystals and sample destruction, respectively); solution provided by cryo-electron microscopy; benefits of cryo-EM; the three pioneers of cryo-EM; using the method to explore complex structures of proteins, cell structures, and viruses
- **Fast Fourier Transform (FFT) and Applications** (by Jonah Philion): the utility of Fourier space and an example; more examples of sound in Fourier space; history of the Fast Fourier transform and time-dependent signals; $\mathcal{O}(n^2)$ versus $\mathcal{O}(n \log n)$ computation time; example applications of the FFT; PaulStretch; speech recognition
- **The Development and Impact of the Blue LED** (by Bryce Primavera): electrons and holes in light emitting diodes (LEDs); band gaps and the red and yellow light released from a diode; problems with using gallium nitride to create the blue LEDs; first breakthrough was growing high quality gallium nitride crystals; second breakthrough was learning how to dope high quality the crystals; heterostructures of LED; why the blue LED is important; energy efficiency of LEDs

11 Monday, November 13

- We reviewed basic tips and standards of display for poster presentations. Prominent in the discussion were:
  - **Medium matters:** Your poster is NOT a research paper in tiles. Don't let text dominate the layout. Make use of the space you have to communicate something that could be understood in less than 10 minutes.
  - **Setting expectations:** People are not going to walk away with a profound understanding of your research. The best you can hope for is that they walk away being interested in your question or analysis and they want to contact you later and look up your work.
  - **Preference for landscape:** Landscape posters generally look and read better than portrait posters (This is a matter of taste of course).
  - **A focal figure:** Having a large important figure in the center of the poster reduces buy-in for viewers.
  - **Practice for flexibility:** Try to think of three levels of explanations contingent on the viewer: One for casual viewers, one for those who are interested in the study but who don?t know the details, and one for those who are interested specialists.
    - You will likely not encounter all three types of people, but knowing your presentation at these different levels will allow you to flexibly construct explanations on the fly.
  - **Greeting:** You can greet people who walk by, but don't launch into an unprompted spiel. Wait for them to ask a specific question.
  - **Sources of Financial Support:** Acknowledge the source of financial support of the work in the acknowledgments
  - **Hot magenta is not your friend:** Glaring colors (e.g., a combination of hot magenta and green) are off putting
  - **Dress code** Be cognizant of the dress code norms for your discipline in general and the conference in particular. Being on either side of the bandwidth of acceptable dress will warrant you looks.
  - **Citations please!** Most science is evolutionary not revolutionary. Be generous in your citations for related work
  - **Test legibility:** Print a font sample for your poster, place it on a wall and standard two meters back to test if its still readable.

12 Monday, November 20

- Student Peer Review of Preliminary Poster Designs

13 Monday, November 27

- Poster Session @ Physics Colloquium!

Tips/Recommendation for Future Teaching Staff

- Instead of a ten-point grading system, it is probably better to have a four-point grading system for assignments: 4 for at least very good; 3 for good; 2 for average; 1 for marginally completed; 0 for incomplete. Communicate this rubric to the students at the beginning. Remove one point for each day an assignment is late.
- Communicate and be strict in imposing 6 minute rule for presentations. Contingent on class size, this is necessary to ensure class ends on time.
- The links for the ”Policy guidelines” assignment are old and dead. They should be replaced.
- Find a new and more modern set of articles for the ”Poster Presentation Review” assignment. The ”Posters for Scientific Meetings” document should especially be replaced.
- Contact Carol (and specifically Carol) about final poster session in the library.

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