PHYSICS 107 - 21st Century Concepts of Space, Time, and Matter", or "Physics: Origins, Content, and Impact on Culture and Society"

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Office hours Tu-Th 1:30-3:30; or whenever I am there (usually daily 10:30-4); or by appointment.

There is no single book for the course - the course pack will have two parts. The lectures will be based on the first part, for which the course pack is strongly recommended. It records all derivations. The second part is a text version, recommended for those who would like to read the material in book-like form to help understanding. The course pack covers about 3/4 of the course. The last quarter will be based on my book *Supersymmetry and Beyond.* A few books will be suggested for backup for different parts of the course, and some for general reading on some topics. There will be a CTools website.

Lectures will include some high school math (algebra, geometry, trigonometry) used to enrich content (but tests and homework will not depend on the math). It is important to include the math in order to demonstrate the powerful effect of mathematics on science, particularly that one can start from an agreed point, go through some steps each of which is clearly acceptable, and see a surprising and exciting new result emerge, one that would not be otherwise convincing. Also, we will see that some concepts are clearer when stated mathematically as well as verbally.

Prerequisites - the course is for any curious person. Science and/or math background ok but not needed. Normally classes are lectures (with questions and discussion).

Goals:

- **Learn some physics, not too much - the main concepts. Learn enough to discuss "big questions" meaningfully.**
- **What is physics (and science in general)? How does it work? Why do we accept/believe the results? Are the results true?**
- **How did we get from a world with no science or understanding of anything in the natural world about four centuries ago (when Shakespeare wrote) to one today with remarkable understanding of the physical universe?**
- **What do we know about "big questions" such as what are we made of, how did our universe originate, why are things like ESP not consistent with known laws of nature.**

Grading and administrative aspects:

- **Absolute standards - everyone can do well if a high grade is justified by performance on the tests, and homework.**
- **Class participation - important, particularly since there is no good book covering all the material.**
- **Two tests -the better test 30% of total score, the less good one 20% One is focused on physics material, one on material about history and how physics works - both after about ¾ of the semester.**
- **Three homework sets, each due one week after being handed out. Two are 15% each, the third 20%**

Physics 107 SYLLABUS – Each entry is approximately one class – last chapters from my book *Supersymmetry and Beyond (foreword by Edward Witten)*

--**How did we get from no science to now?** – Greeks argued people can understand the natural universe – examine how science works, its validity and truth – definitions of science and technology – science not same as technology – could have world with technology but not science – start almost at beginning, cave paintings, ice ages, alphabet

--**Why science developed in Ionian Greece** – role of small diverse city states, merchant ecomomy, alphabet, no strong religious or administrative structure and more – why science did not arise in China and other civilizations – how can we decide who is right? – some basic laws of nature are always valid, forever – others improve as they are understood better – how to do science learned as it is done – results accumulate and improve – Plato, Aristotle, Lucretius – Library at Alexandria, Hypatia – Eratosthenes and the size of the Earth – weaknesses of Greek science – transition to modern science

–**Kepler's Laws** – the first equation ever – Galileo's telescope – changes in the Heavens – motion, difficult problem – what needs explaining – some numbers, symbols, notation – Galileo formulated and tested hypotheses

--**Why did the transition to modern science occur?** – Why then (around 1600)? – Columbus to Copernicus to Kepler, Galileo to Newton – Newton's laws of motion and of gravitation – explains (derives, incorporates) results of Kepler, Galileo – the moon doesn't fall to the earth! – new idea – motion in the heavens and motion on earth obey same laws, derived with simple high school math, so compelling – **extraordinary impact on culture, society, forming the modern world!**

--**Led to**: tides – discovery of Neptune, first major prediction of a new part of nature – Halley's comet, universe indifferent, "downfall of superstition" – speed of light – heat and motion unified – concept of fields – dark matter – galaxy formation – star formation – satellites – going to the moon – historical dating and perspectives – Enlightenment, modern economics (via Adam Smith), modern forms of government via Locke, Jefferson, Adams – *universal* human rights

--**Newton's third law** – what is force? – why doesn't a pencil fall through a table? – unification of forces? – Aristotle, Galileo different but both right – Galileo method more right

--**Electricity and magnetism** – except gravity, everything that affects us is from the electromagnetic force (EM) – **all senses** – Benjamin Franklin top scientist, intellectual leader, big impact – changing electricity and changing magnetism related! – Faraday, many contributions, particularly idea of electromagnetic fields – profoundly changed how we think – Maxwell's equations, full mathematical unification – without Maxwell's equations, maybe no TV, no modern computers, and much more – led to understanding light (classically) and speed of light

--**Energy in nature and in human history** – Major simplifying and unifying concept – forms of energy – conservation of energy, first law of thermodynamics – some things are impossible – some units and numbers – binding energy, negative energy – entropy, increases, second law of thermodynamics – efficiencies

--**Earth's energy budget** – fission, fusion, solar power – solar power – efficiencies, food chain – photosynthesis – energy intensity – input-output

--**Special Relativity** – velocity addition different for Newton, Maxwell (correct) – correct equation gives speed of light plus any speed equals speed of light! – obvious with high school algebra, hard to believe otherwise – two assumptions: speed of light same in all inertial frames, and laws of nature same in all inertial frames – implies two events can be simultaneous in one frame but not in another – implies moving clocks (including heart) tick slower – very well tested – $E=mc^2$

--**Atoms** – very controversial idea, very emotional – Bruno burned at stake in 1600 – how small are atoms? –Franklin could have deduced size in late 1700s but not finally done till 1908 – how see atoms? – Mendeleev, Periodic Table – atomic spectra, tells us what stars across the universe are made of – atom has a nucleus! – energy comes in quantized chunks – understanding atoms and chemistry

--**Magnetism understood! – Atoms understood!** - uncertainty principle – virtual particles – Bell's theorems – transitions among atomic energy levels

--**Fundamental constituents**? – not atoms – nuclei? – no – curve of binding energy – fusion – fission – radioactivity – natural environment – half-lives – events without causes – human cancer from proton decay? – uses of radioactivity

--**The size of things** – Galileo, sensed limits on size implied radius of atom fixed by basic physics, remarkable insight

--**Why do we believe scientific results?** – some areas of science are understood – the relevant laws will never change, for example classical electromagnetism, or the properties of atoms, or that we are made of atoms, the number of stable chemical elements – to trust results a theory is needed that ties different aspects together – how results get tested, especially important ones – the Sokal affair – why science done by imperfect humans leads to the most certain knowledge we have

--**Evolution of the universe** – measuring cosmological distances – identifying atoms by spectral lines – Doppler shift, red shift – Olber's "paradox", could have learned universe was expanding when Newton, Halley, and Roemer met in 1679 in London – big bang, evidence – nucleosynthesis – conditions for universes to occur – inflation – Planck scales

--**Star formation** – planets – **dark matter**, detecting dark matter – **CMB radiation –** dark energy – universality of laws of nature – Oklo natural reactor – how universes might originate – the multiverse

--**Search for extraterrestrial intelligence** – became scientific in 1960s – very professional now – few thousand planets seen, many more soon – probably only carbon based life possible – how communicate? – very few *scientific* civilizations? – traveling to other civilizations? – why is SETI important?

--**Deterministic chaos, determinism** – success of Newton's laws seemed to imply could calculate future behavior of everything – turned out not so when measurement errors or uncertainty present – or if equations nonlinear – simple examples – butterfly effect – impact on free will vs determinism

--**Pseudoscience, anti-science** – how do we know astrology is nonsense? – that electromagnetic radiation from cell phone will not harm us? – is everything possible? – some impossible things – what determines what can happen in the universe – extrasensory perception does not happen – some things we know for sure – homeopathic cures don't work – understanding coincidences

CHAPTER 1 — Toward the Big Questions – To understand nature we need to know the particles, forces, and rules — Research in progress (RIP) — Equations? – World described by solutions! — Prediction, postdiction, and testing — Where are the superpartners? — *The boundaries of science have moved*

CHAPTER 2 — A Little Bit About The Standard Model Of Particle Physics – The forces — Mass, decays, and quanta — The particles: Do we know the fundamental constituents? (yes) — Particles and fields — There are more particles: antiparticles, neutrinos, more quarks and leptons, Higgs bosons — New ideas and remarkable predictions of the Standard Model — Experimental foundations of the Standard Model — Spin, fermions, and bosons — Beyond the Standard Model

CHAPTER 3 — Why Physics Is The Easiest Science — Effective Theories – Understanding the world one piece at a time — Organizing effective theories by distance scales — Supersymmetry is an effective theory too — The Physics of the Planck scale — The human scales

CHAPTER 4 — Supersymmetry and Sparticles – What Supersymmetry Adds – What is supersymmetry? — Why do so many physicists expect supersymmetry to be observed experimentally soon? — The superpartners — Supersymmetry as a space-time symmetry, superspace — Hidden or “broken” supersymmetry

CHAPTER 5 — Testing Supersymmetry Experimentally – Detectors and colliders — Collisions produce previously unknown particles — Recognizing superpartners — Sparticles: their personalities, backgrounds, and signatures — Future colliders — Can we do the experiments we need to do?

CHAPTER 6 — What Is The Universe Made Of? – What particles are there in the universe? — Is the lightest superpartner the dark matter of the universe?

CHAPTER 7 — Why Is Higgs Physics So Exciting And Important – The Higgs field, the Higgs mechanism, Higgs bosons – Not the Standard Model Higgs boson

CHAPTER 8 — M/string Theory – Extra small dimensions – What is M/string theory? – Testing M/string theory – Hidden or broken or partial supersymmetry – The role of data

CHAPTER 9 — How Much Can We Understand? – Testing M/string theory and the final theory – Practical limits? – Anthropic questions and string theory – The Cosmological Constant – The role of extra dimensions – The end of science?

107 THEMES

• Once there was no science, no understanding of how nature worked at all- when Shakespeare wrote. Now we understand a huge amount. How did we get from there to here?

• Science is figured out by people. Why are the results of science agreed on by all knowledgeable people from all cultures and backgrounds?

• We now understand the physical world we can see back to the beginning, out to the edges, all domains. Laws of nature are same everywhere.

• The earth orbits the sun, not the other way around. Similarly, lots of aspects of nature can be counterintuitive - light we don't see with our eyes, perhaps extra dimensions, etc.

• People can learn how the natural universe works, and understand it.

• Aim to learn enough about physics and about how it works, but not too much

Three eras of science since Galileo, Kepler

- **Classical**
- **Modern – quantum theory, special relativity, Standard Model (strong, weak, and electromagnetic forces, quarks and leptons), big bang**
- **No name – maybe “postmodern” – Beyond the Standard Model, Higgs physics, supersymmetry, extra dimensions, inflation, dark matter, string/M theory, dark energy, multiverse**