Modern Physics
Overview

Today

I. What is Modern Physics? Syllabus
II. How will we navigate the 'Modern' period?

I. What is Modern Physics?

We call the period beginning roughly at the turn of the 20th century up until somewhere in the middle of the 1900's the era of Modern Physics. The moniker 'Modern' is deserved as there were several significant departures from the previously prevailing themes of mechanics during this period. This has also led us to refer to mechanics before 1900 as classical mechanics.

Our syllabus outlines the three revolutions that we will study with the most care: Special Relativity, Thermodynamics & Statistical Mechanics, and Quantum Mechanics.

II. How will we navigate the 'Modern' period?

As you might imagine, these three revolutions cover quite a swath of Nature. To aid us in tying the topics together and to keep us oriented we will continually return to the questions: How do light and matter interact and what do we learn about each from these interactions?

We begin with light and the Special Theory of Relativity. Special Relativity has many of the same hallmarks of the other revolutions—a rethinking of foundational notions, new connections with observations, and new computational tools—but, it achieves all of this in a quite self-contained manner and with a minimum of inputs, which make it a good place to start. Despite its seeming simplicity Special Relativity will force us to reconceptualize our foundational notions of time and space.

Light also naturally leads us into the study of classical waves. A wave is something that transports energy and momentum through space with surprising subtlety. The quantitative study of waves provides an invaluable mental model that we will return to again and again in this course and throughout your study of physics.
We will also use this review of waves as an excuse to explore the mathematical tool of complex numbers. Complex numbers encode waves efficiently and are particularly essential when we turn to quantum theory in the last part of the course.

Most waves are supported by a medium through which they move, for example a block of metal or a gas. At this point in the course we will turn our attention towards understanding these material media. As physicists started to take the atomic hypothesis seriously, they had to confront the fact that materials were made of vast collections of atoms or molecules, exceeding 10^{23} in number. Even a brief attempt will convince you that it is hopeless to track the motion of each of these constituents and instead attention turned to those few variables that remain coherent even in this vast sea of constituents, things such as volume, pressure, temperature, energy, and entropy. The study of these macroscopic observables was termed Thermodynamics. While stunningly empirically successful, Thermodynamics continues to feel opaque without any reference to the atomo-molecular motions that give rise to its laws. Thus, a continuous dialogue between the microscopic and macroscopic descriptions opened up and the statistical phenomena that lead to Thermodynamics' laws are called Statistical Mechanics. Using these tools we will start to construct a rich landscape of material behaviors and phenomena.

Having understood some things about light and about matter separately we will attempt to understand what happens when they begin to exchange energy with one another. In particular, we will explore whether light and matter can be in thermal equilibrium, neither the material body nor the radiation giving up more energy to the other. It turns out that this is possible(!) and that it describes all sorts of things from ovens to stars.

Amidst all of these ideas, careful observation of the interaction of light with single-component gases and metals showed that they exchange energy in discrete packets and completely changed how we think about matter. This was the advent of Quantum Mechanics. In particular, it was realized that it was not justified to described a material particle as a little ball with definite mass, position, and momentum. Instead, matter too has a wave-like nature, but a surprisingly subtle one where a particle's position and momentum are described through waves of probability. This brings us back to our foundational studies in waves from the beginning of the course and to our study of probability and statistics from the heart of the course. Quantum Mechanics, in turn, helps to clarify the foundations of the statistical ideas we used to describe matter.

The interaction of light and matter is stunningly rich! I think you will enjoy its study immensely. However, you will have to exercise some patience as many of the ideas that we will explore will speak to one another both forwards and backwards in the course and will potentially only fit together nicely in the end. Know that you are experiencing only a fraction of the challenge and confusion that those pioneering these ideas had to. Indeed, many working Physicists feel that we still don't understand the foundations of quantum mechanics and that we must content ourselves for the moment with its stunning empirical successes. Hopefully, one of you will ultimately bring deeper coherence to the themes we will explore in this course!