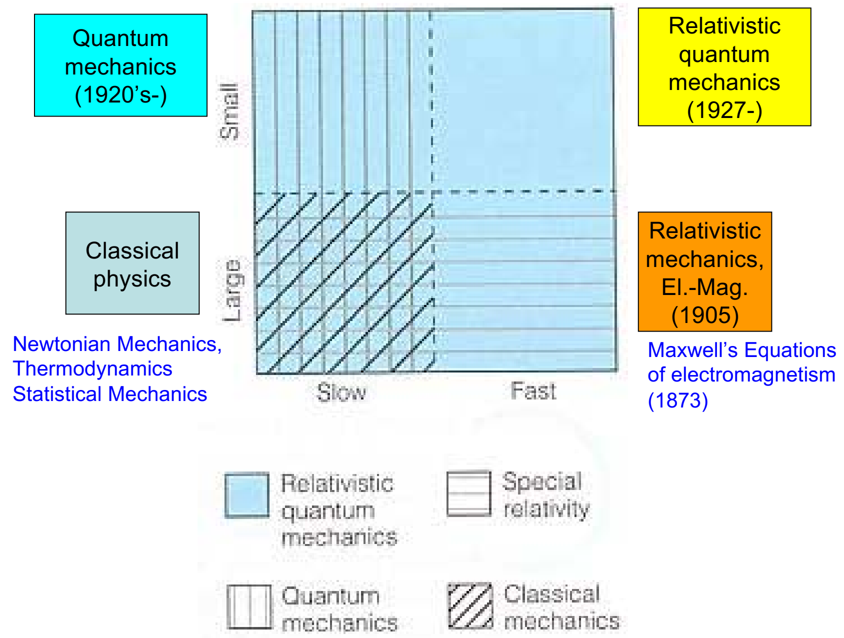
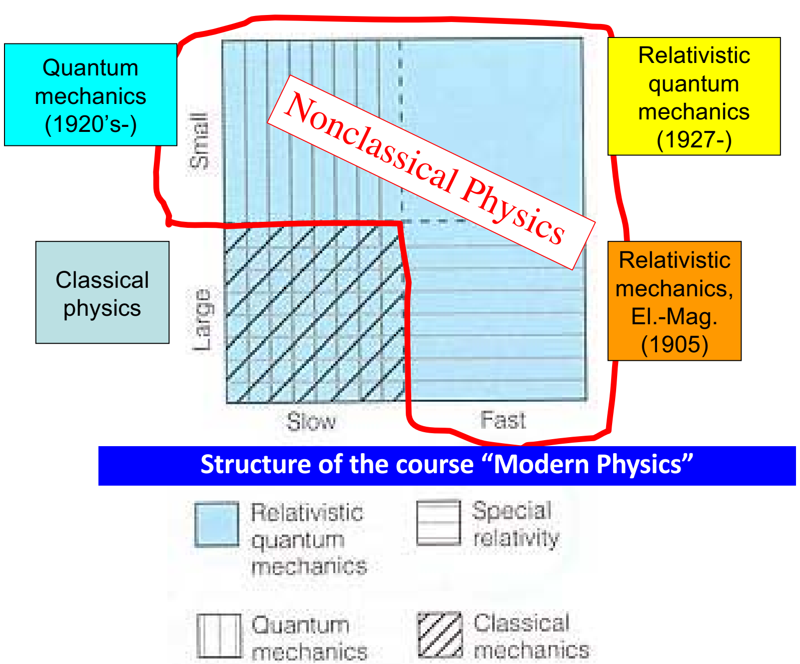
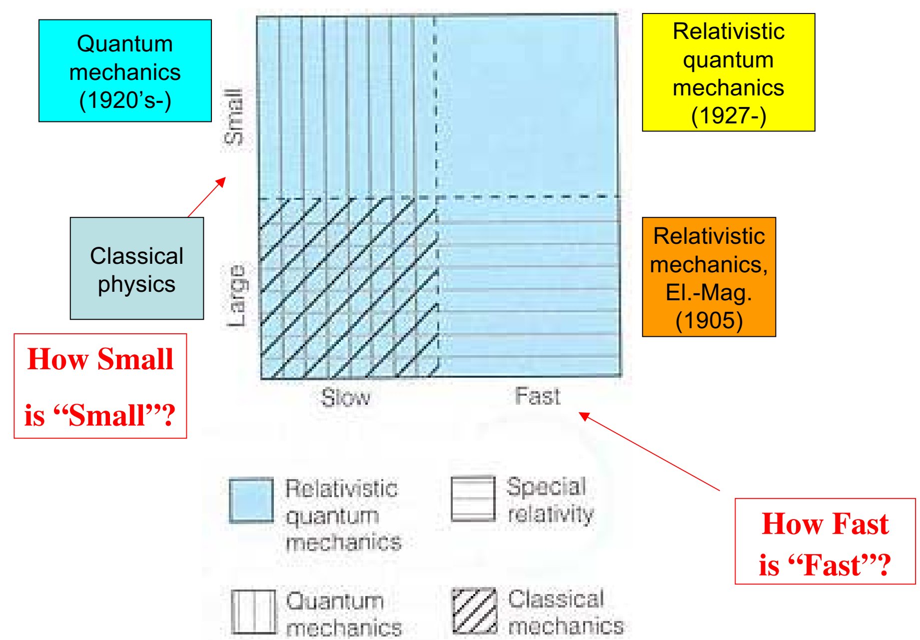
PHYS-3301

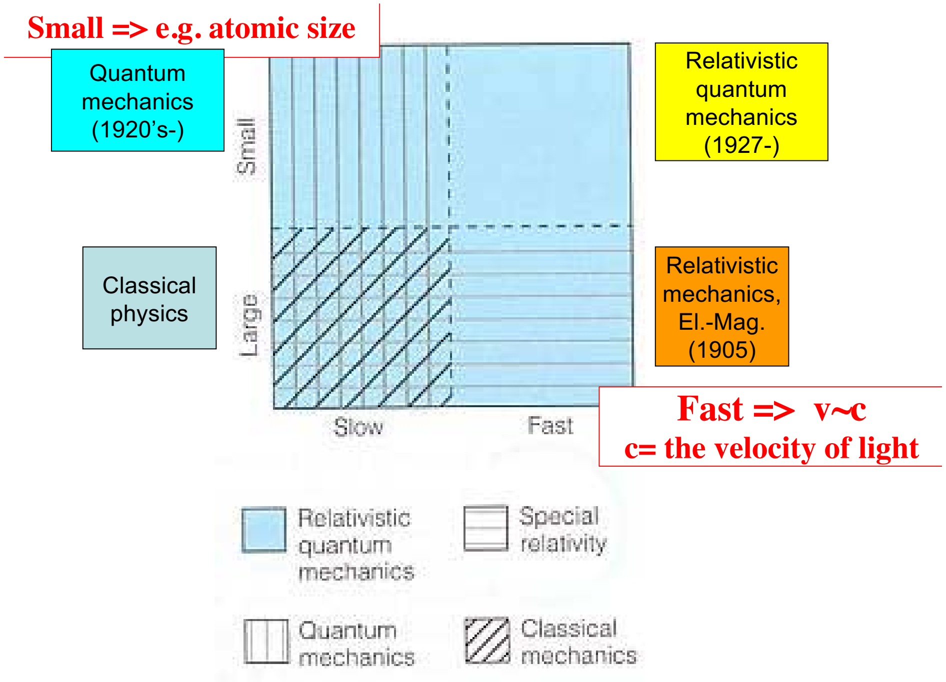
Lecture 2

Aug. 27, 2024



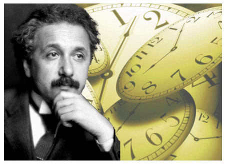
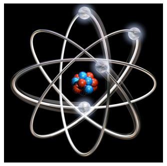






Modern Physics

- Two basic ideas
  - Time and space are not absolutes.
  - **Particles behave like waves and waves behave like particles.**
- Two branches
  - Special Relativity
  - **Quantum Mechanics**

With an understanding of these branches, we can then explore areas of modern physics such as superconductivity, modern optics, nuclear physics, particle physics and cosmology - along with a host of other areas of science.

Chapter. 3 Wave & Particles I

EM-"Waves" behaving like "Particles"

Outline:

- **Blackbody Radiation (Plank; 1900; 1918*)**
- **The Photoelectric Effect (Einstein; 1905; 1921*)**
- **The Production of X-Rays (Rontgen;1901; 1901*)**
- **The Compton Effect (Compton; 1927; 1927*)**
- **Pair Production (Anderson; 1932; 1936*)**
- **Is It a Wave or a Particle? → Duality?**

Chapter. 4 Wave & Particles II

"Matter" behaving as "Waves"

Outline:

- A Double-Slit Experiment (watch "video")
- Properties of Matter Waves
- The Free-Particle Schrödinger Equation
- **Uncertainty Principle**
- **The Bohr Model of the Atom**
- **Mathematical Basis of the Uncertainty Principle – The Fourier Transform**

Chapter. 5
Bound States: Simple Case

Purpose:

- **To make QM useful in real application,**
- **we must have a way to account for the effects of external forces****

Let's start with the Schrödinger eq. to include these effects.

**** interaction of object with its surrounding**

Chapter. 5
Bound States: Simple Case

Outline:

- **The Schrödinger Equation (for interacting particles)**
- **Stationary States**
- **Physics Conditions: Well-Behaved Functions**
- **A Review of Classical Bound States**
- **Case 1: Particles in a Box – The Infinite Well**
- **Case 2: The Finite Well**
- **Case 3: The Simple Harmonic Oscillator**
- **Expectation Values, Uncertainties, and Operators**

Chapter. 6
Unbound States

Outline:

- The Potential Step
- The Potential Barrier & Tunneling
- Alpha Decay & Other Applications
- Particle-Wave Propagation

Chapter. 7
QM in 3-dims & Hydrogen Atom

Outline:

- The Schrödinger Eq. in 3-Dimensions
- The 3D Infinite Well
- Energy Quantization & Spectral Lines in Hydrogen
- The Schrödinger Eq. for a Central Force
- Angular Behavior in a Central Force
- The Hydrogen Atom
- Radial Probability
- Hydrogen-like Atoms

Chapter. 8
Spin & Atomic Physics

Outline:

- Evidence of Angular Momentum Quantization
- Identical Particles
- The Exclusion Principle
- Multi-electron Atoms & the Periodic Table
- Characteristic X-Rays

It's open said that in Q.M. there're only 3 bound-state problems solvable (w/o numerical approximation tech.)
1. Infinite well, 2. Harmonic oscillation, 3. hydrogen atom
– all 1-particle problem.
Most real application: multiple system. so, let's start an atom with multiple electrons

Chapter. 9
Statistical Mechanics

Statistical mechanics is NOT non-classical or modern physics in the same sense that special relativity and QM are. Rather, it's a distinct area of physics that applies to many others; either classical or QM.

Q:: Why study it now? A:: many modern physics require it.
e.g. A gas laser: thermodynamics system of gas molecules
A semiconductor: thermodynamics system of atom bound in a solid lattice

**** Thermodynamic system = countless particles; precise average behavior.**

Chapter. 9
Statistical Mechanics

Outline:

- Historical Overview
- The Boltzmann Distribution
- Maxwell Velocity Distribution
- Equipartition Theorem
- Maxwell Speed Distribution
- Classical and Quantum Statistics
- Fermi-Dirac Statistics
- Bose-Einstein Statistics

Chapter. 10
Molecules and Solids

Outline:

- 10.1 Molecular Bonding and Spectra
- 10.2 Stimulated Emission and Lasers
- 10.3 Structural Properties of Solids
- 10.4 Thermal and Magnetic Properties of Solids
- 10.5 Superconductivity
- 10.6 Applications of Superconductivity

In Chapter 7 & 8, we learned about the properties of individual atoms. This chapter builds on that knowledge to find out what happens when those atoms join together to form molecules & solids.

Chapter. 11
Semiconductor Theory and Devices

Outline:

- 11.1 Band Theory of Solids
- 11.2 Semiconductor Theory
- 11.3 Semiconductor Devices
- 11.4 Nanotechnology

In Chapter 10 you learned about structural, thermal, and magnetic properties of solids. In this chapter we concentrate on electrical conduction.

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Historical Development

Newton(1704): light as a stream of particles.

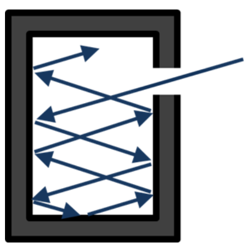
Descartes (1637), **Huygens**, **Young**, **Fresnel** (1821), **Maxwell**: by mid-19th century,the wave nature of light was established (***interference*** and ***diffraction***, transverse nature of EM-waves).

Physics of the 19th century: mostly investigation of light waves
Physics of the 20th century: interaction of light with matter

One of the challenges – understanding the "black body spectrum" of thermal radiation

Black body:
In physics, a black body is an idealized object that absorbs all incident E&M radiation.
No E&M radiation passes through the black body and none is reflected.
Because no light is reflected or transmitted, the object appears black when it is cold.

An approximate realization of a black body as a tiny hole in an insulated enclosure



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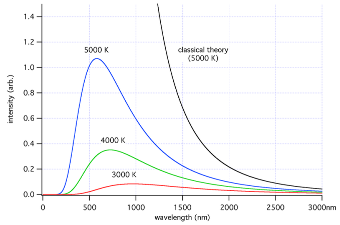
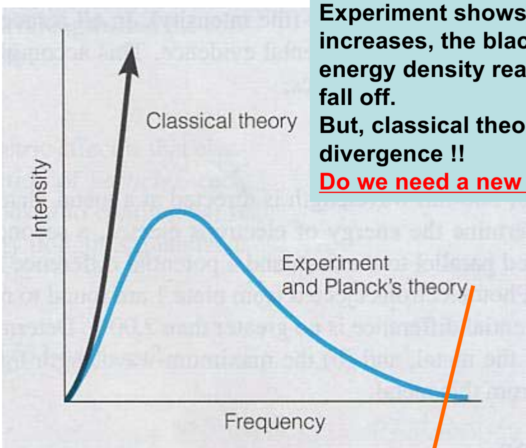
Black body:
In physics, a black body is an idealized object that absorbs all incident E&M radiation
No E&M radiation passes through it and none is reflected.
Because no light is reflected or transmitted, the object appears black when it is cold.
However, a black body emits a temperature-dependent spectrum of light. (see Fig.)
This thermal radiation from a black body is termed black-body radiation.

As the temperature decreases, the peak of the black-body radiation curve moves to lower intensities and longer wavelengths.



Black Body Radiation

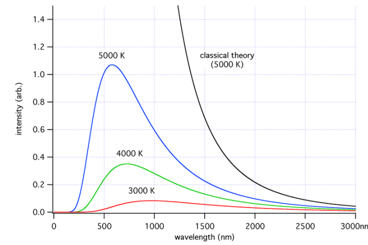
(Max Planck 1900)



Experiment shows that as frequency increases, the blackbody spectral energy density reaches a max. then fall off.
But, classical theory predicts a divergence !!
Do we need a new theory?

(More in Appendix C)

Historical Development



In 1900, **Planck** suggested a solution based a revolutionary new idea:
Emission and absorption of E&M radiation by matter has **quantum nature**:
i.e. **the energy of a quantum of E&M radiation** emitted or absorbed by a harmonic oscillator with the frequency ***f*** **is given by the famous Planck's formula**

$E = h f$,where ***h*** is the Planck's constant $h \approx 6.626 \times 10^{-34} J \cdot s$

- at odds with the "classical" tradition, where energy was always associated with amplitude, not frequency

Also, in terms of the angular frequency $\omega = 2\pi f$ $E = \hbar\omega$ where $\hbar = \frac{h}{2\pi}$ $\hbar \approx 1.05 \times 10^{-34} J \cdot s$

The Planck's Black-Body Radiation Law:

The Energy (*E*) in the electromagnetic radiation at a given frequency (*f*) may take on values restricted to

$$E = nhf$$

where:
n = an integer
h **= a constant** $h \approx 6.626 \times 10^{-34} J \cdot s$
("Planck Constant")