PHYS 3313 – Section 001
Lecture #2

Wednesday, Aug. 29, 2012
Dr. Jaehoon Yu

- Classical Physics
- Kinetic Theory of Gas
- Concept of Waves and Particles
- Conservation Laws and Fundamental Forces
- Atomic Theory of Matter
- Unsolved Questions of 1895 and New Horizon

Announcements

- Reading assignment #1: Read and follow through appendices 3, 5, 6 and 7 by Tuesday, Sept. 4
  - There will be a quiz next Wednesday, Sept. 5, on this reading assignment
- Nobel laureate, Steven Weinberg, will give a public lecture at 7:30pm, Wednesday, Oct. 24
  - Required attendance!

Special Project #1

1. Compute the electric force between the two protons separate the farthest in an intact U^{238} nucleus. Use the actual size of the U^{238} nucleus. (10 points)
2. Compute the gravitational force between the two protons separate the farthest in an intact U^{238} nucleus. (10 points)
3. Express the electric force in terms of the gravitational force. (5 points)

- You must look up the mass of the proton, actual size of the U^{238} nucleus, etc, and clearly written on your project.
- You MUST have your own, independent answers to the above three questions even if you worked together with others. All those who share the answers will get 0 credit if copied.
- Due for the submission is Monday, Sept. 10!

Why do Physics?

Exp. {
- To understand nature through experimental observations and measurements (**Research**)

Theory {
- Establish limited number of fundamental laws, usually with mathematical expressions
- Predict the nature's course

⇒Theory and Experiment work hand-in-hand

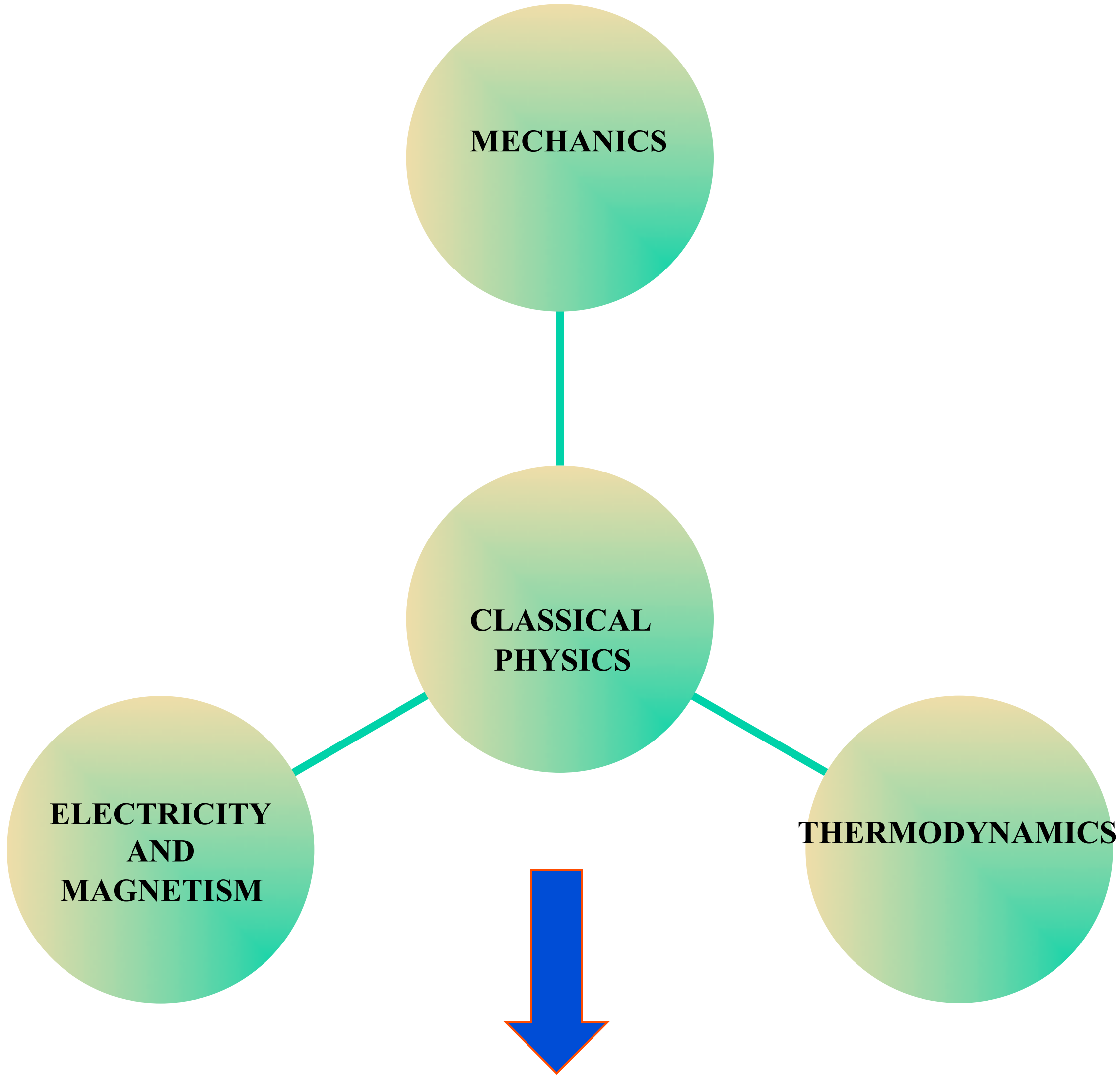
⇒Theory works generally under restricted conditions

⇒Discrepancies between experimental measurements and theory are good for improvements

⇒Improves our everyday lives, even though some laws can take a while till we see them amongst us

Brief History of Physics

- AD 18th century:
  - Newton's Classical Mechanics: A theory of mechanics based on observations and measurements
- AD 19th Century:
  - Electricity, Magnetism, and Thermodynamics
- Late AD 19th and early 20th century (Modern Physics Era, after 1895)
  - People thought everything was done and nothing new could be discovered
  - Concept of atoms did not exist
  - Few problems not well understood late 19th century became the basis for new discoveries in 20th century
  - That culminates in understanding of phenomena in microscopic scale and extremely high speed approaching the speed of light
  - Einstein's theory of relativity: Generalized theory of space, time, and energy (mechanics)
  - Quantum Mechanics: Theory of atomic phenomena



CONSERVATION LAWS

Triumph of Classical Physics: The Conservation Laws

- **Conservation of energy**: The total sum of energy (in all its forms) is conserved in all interactions.
- **Conservation of linear momentum**: In the absence of external forces, linear momentum is conserved in all interactions.
- **Conservation of angular momentum**: In the absence of external torque, angular momentum is conserved in all interactions.
- **Conservation of charge**: Electric charge is conserved in all interactions.

Mechanics

- Galileo (1564-1642)
  - First great experimentalist
  - Principle of inertia
  - Established experimental foundations

Isaac Newton (1642-1727)

Three laws describing the relationship between mass and acceleration.

- **Newton's first law** (*law of inertia*): An object in motion with a constant velocity will continue in motion unless acted upon by some net external force.
- **Newton's second law**: Introduces force (F) as responsible for the the change in linear momentum (p):

$$\vec{F} = m\vec{a} \quad \text{or} \quad \vec{F} = \frac{d\vec{p}}{dt}$$

- **Newton's third law** (*law of action and reaction*): The force exerted by body 1 on body 2 is equal in magnitude and opposite in direction to the force that body 2 exerts on body 1.

$$\vec{F}_{21} = -\vec{F}_{12}$$

Electromagnetism

Contributions made by:

- Coulomb (1736-1806)
- Oersted (1777-1851)
- Young (1773-1829)
- Ampère (1775-1836)
- Faraday (1791-1867)
- Henry (1797-1878)
- Maxwell (1831-1879)
- Hertz (1857-1894)

Culminates in Maxwell's Equations

- In the absence of dielectric or magnetic materials, the four equations developed by Maxwell are:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$

Gauss' Law for electricity

A generalized form of Coulomb's law relating electric field to its sources, the electric charge

$$\oint \vec{B} \cdot d\vec{A} = 0$$

Gauss' Law for magnetism

A magnetic equivalent of Coulomb's law relating magnetic field to its sources. This says there are no magnetic monopoles.

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Faraday's Law

An electric field is produced by a changing magnetic field

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl} + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

Generalized Ampére's Law

A magnetic field is produced by an electric current or by a changing electric field

Thermodynamics

Deals with temperature, heat, work, and the internal energy of systems

Contributions made by:

- Benjamin Thompson (1753-1814)
- Sadi Carnot (1796-1832)
- James Joule (1818-1889)
- Rudolf Clausius (1822-1888)
- William Thompson (1824-1907)

Primary Results

- Introduces thermal equilibrium
- The first law establishes heat as energy
- Introduces the concept of internal energy
- Interprets temperature as a measure of internal energy
- Generates limitations of the energy processes that cannot take place

The Laws of Thermodynamics

- **First law**: The change in the internal energy ΔU of a system is equal to the heat Q added to a system plus the work W done by the system ➔ Generalization of conservation of energy including heat

$$\Delta U = Q + W$$

- **Second law**: It is not possible to convert heat completely into work without some other change taking place.
- **The "zeroth" law**: Two systems in thermal equilibrium with a third system are in thermal equilibrium with each other.
  - Explicitly stated only in early 20th century
- **Third law**: It is not possible to achieve an absolute zero temperature.

The Kinetic Theory of Gases

Contributions made by:

- Robert Boyle (1627-1691) → PV = constant (fixed T)
- Jacques Charles (1746-1823) & Joseph Louis Gay-Lussac (1778-1823) → V/T=constant (fixed P)
- Culminates in the **ideal gas equation** for *n* moles of a "simple" gas:

$$PV = nRT$$

(where *R* is the ideal gas constant, 8.31 J/mol · K)

- We know now that gases consist of rapidly moving atoms and molecules, bouncing off each other and the walls!!

Additional Contributions

- Amedeo Avogadro (1776-1856) ➔ Hypothesized in 1811 that the equal V of gases at the same T and P contain equal number of molecules ($N_A=6.023 \times 10^{23}$ molecules/mol)
  - 1 mole of Hydrogen molecule is 2g & 1 mole of carbon is 12g.
- John Dalton (1766-1844) opposed due to confusion between his own atomic model and the molecules
- Daniel Bernoulli (1700-1782) ➔ Kinetic theory of gases in 1738
- By 1895, the kinetic theory of gases are widely accepted
- Ludwig Boltzmann (1844-1906), James Clerk Maxwell (1831-1879) & J. Willard Gibbs (1939-1903) made statistical interpretation of thermodynamics bottom half of 19^{th} century

Primary Results of Statistical Interpretation

- Average molecular kinetic energy directly related to absolute temperature
- **Internal energy** *U* directly related to the average molecular kinetic energy
- Internal energy equally distributed among the number of degrees of freedom (*f*) of the system

$$U = nN_A \langle K \rangle = \frac{f}{2} nRT$$

(N_A = Avogadro´ s Number)

- And many others

Concept of Waves and Particles

Two ways in which energy is transported:

- Point mass interaction: transfers of momentum and kinetic energy: *particles*
- Extended regions wherein energy transfers by way of vibrations and rotations are observed: *waves*

Particles vs. Waves

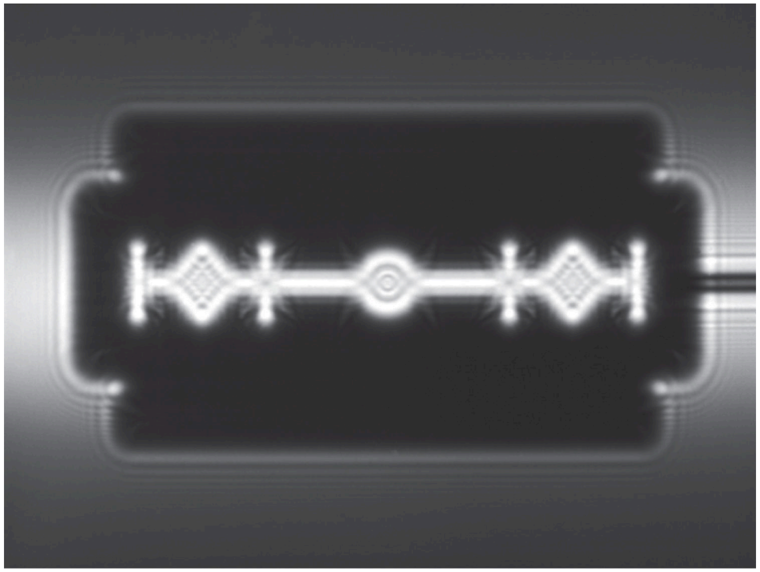
- Two distinct phenomena describing physical interactions
  - Both required Newtonian mass
  - Particles in the form of point masses and waves in the form of perturbation in a mass distribution, i.e., a material medium
  - The distinctions are observationally quite clear; however, not so for the case of visible light
  - Thus by the 17th century begins the major disagreement concerning the nature of light

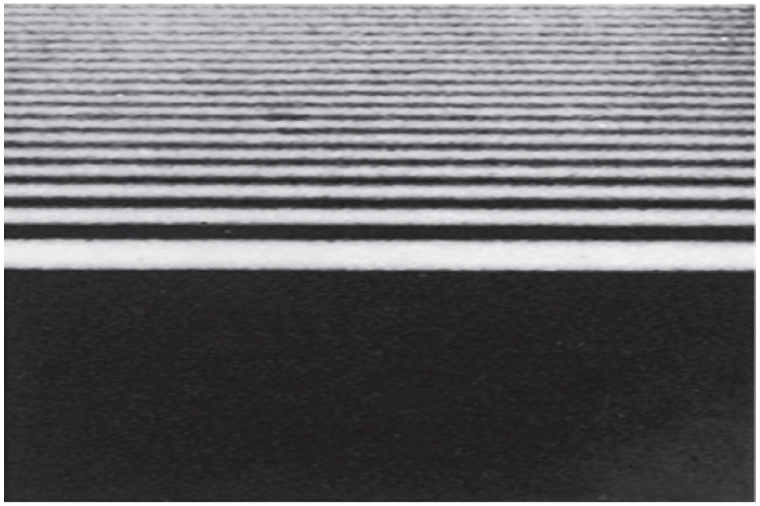
The Nature of Light

- Isaac Newton promoted the corpuscular (particle) theory
  - Published a book "Optiks" in 1704
  - Particles of light travel in straight lines or rays
  - Explained sharp shadows
  - Explained reflection and refraction
- Christian Huygens (1629 -1695) promoted the wave theory
  - Presented theory in 1678
  - Light propagates as a wave of concentric circles from the point of origin
  - Explained reflection and refraction
  - Did not explain sharp shadows
- Thomas Young (1773 -1829) & Augustin Fresnel (1788 – 1829) → Showed in 1802 and afterward that light clearly behaves as wave through two slit interference and other experiments
- In 1850 Foucault showed that light travel slowly in medium, the final blow to the corpuscular theory in explaining refraction

The Wave Theory Advances…

- Contributions by Huygens, Young, Fresnel and Maxwell
- Double-slit interference patterns
- Refraction of light from a vacuum to a medium
- Light was an electromagnetic phenomenon
- Shadows are not as sharp as once thought with the advancement of experimental precision
- *Establishes that light propagates as a wave*





The Electromagnetic Spectrum

- Visible light covers only a small range of the total electromagnetic spectrum
- All electromagnetic waves travel in a vacuum with a speed *c* given by:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \lambda f$$

(where μ_0 and ε_0 are the respective permeability and permittivity of "free" space)

Conservation Laws and Fundamental Forces

- Conservations laws are guiding principles of physics
- Recall the fundamental conservation laws:
  - Conservation of energy
  - Conservation of linear momentum
  - Conservation of angular momentum
  - Conservation of electric charge
- In addition to the classical conservation laws, two modern results will include:
  - The conservation of baryons and leptons
  - The fundamental invariance principles for time reversal, distance, and parity

Also in the Modern Context…

- The three fundamental forces are introduced
  - **Gravitational**: $\vec{F}_g = -G\frac{m_1 m_2}{r^2}\hat{r}$
    - Responsible for planetary motions, holding things on the ground, etc
  - **Electroweak**
    - **Weak**: Responsible for nuclear beta decay and effective only over distances of ~10^{-15} m
    - **Electromagnetic**: Responsible for all non-gravitational interactions, such as all chemical reactions, friction, tension….
    - $\vec{F}_C = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$ (Coulomb force)
  - **Strong**: Responsible for "holding" the nucleus together and effective less than ~10^{-15} m

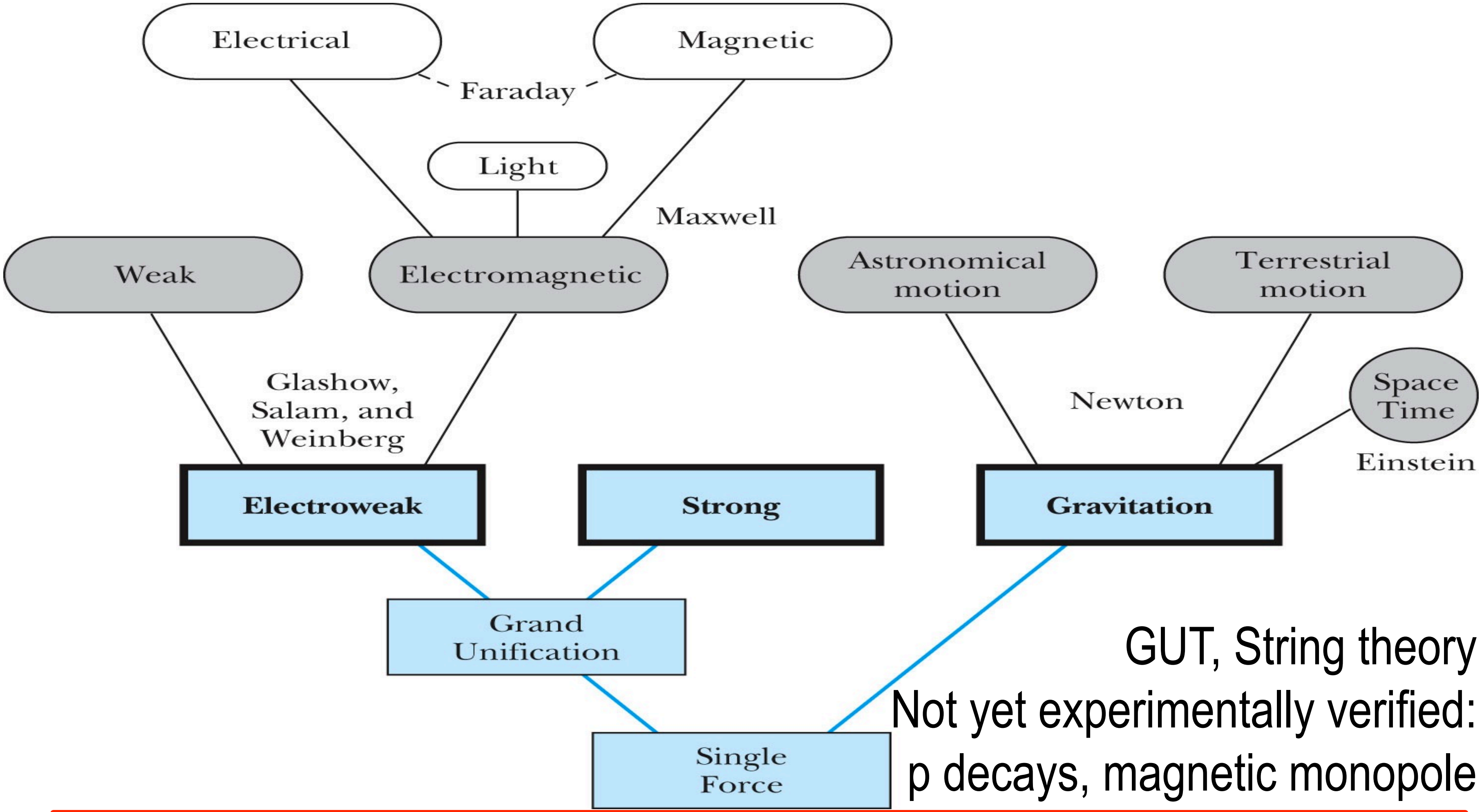
Relative Strength of Fundamental Forces

Table 1.1 Fundamental Forces

Interaction		Relative Strength*	Range
Strong		1	Short, $\sim 10^{-15}$ m
Electroweak	Electromagnetic	10^{-2}	Long, $1/r^2$
	Weak	10^{-9}	Short, $\sim 10^{-15}$ m
Gravitational		10^{-39}	Long, $1/r^2$

*These strengths are quoted for neutrons and/or protons in close proximity.

Unification of Forces



GUT, String theory

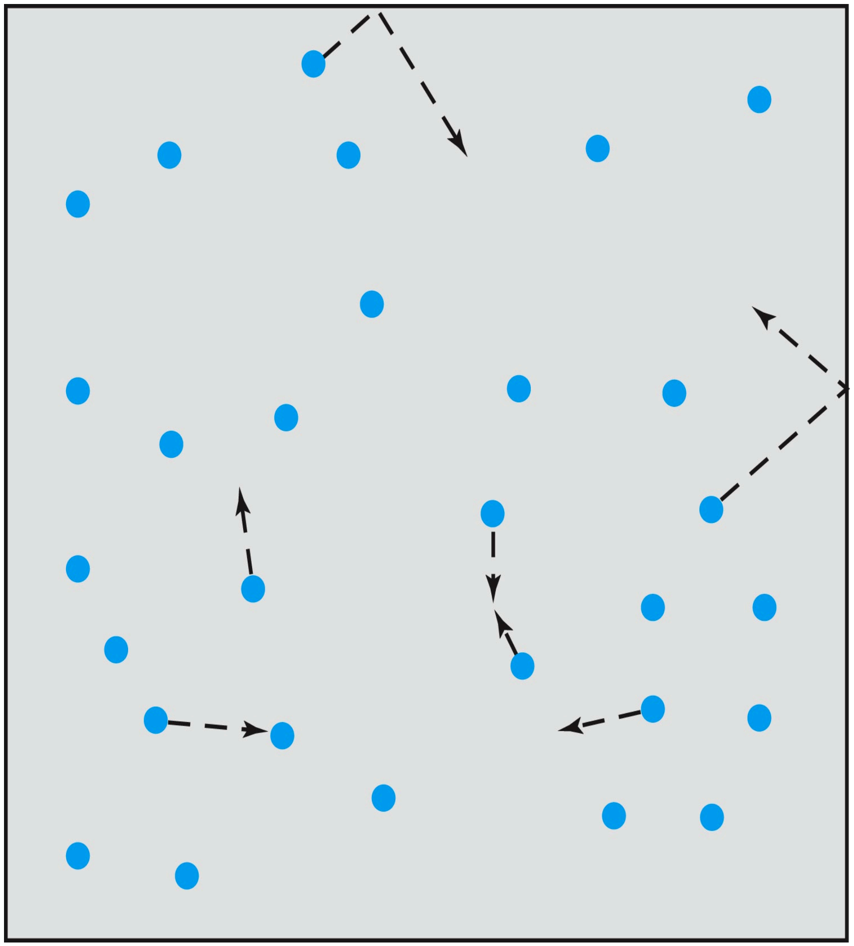
Not yet experimentally verified:

p decays, magnetic monopole

Note: Weinberg is coming for a public lecture at 7:30pm, Wednesday, Oct. 24; "The Standard Model, Higgs Boson, Who Cares?"

Relevance of Gas Concept to Atoms

- The idea of gas (17th century) as a collection of small particles bouncing around with kinetic energy enabled concept of small, unseen objects
- This concept formed the bases of existence something small that make up matter



The Atomic Theory of Matter

- Concept initiated by Democritus and Leucippus (~450 B.C.) (first to us the Greek *atomos*, meaning "indivisible")
- In addition to fundamental contributions by Boyle, Charles, and Gay-Lussac, Proust (1754 – 1826) proposes the **law of definite proportions**
- Dalton advances the **atomic theory of matter** to explain the law of definite proportions
- Avogadro proposes that all gases at the same temperature, pressure, and volume contain the ***same number of molecules (atoms)***; viz. 6.02×10^{23} atoms
- Cannizzaro (1826 – 1910) makes the distinction between atoms and molecules advancing the ideas of Avogadro.

Further Advances in Atomic Theory

- Maxwell derives the speed distribution of atoms in a gas
- Robert Brown (1753 – 1858) observes microscopic “random” motion of suspended grains of pollen in water
- Einstein in the 20^{th} century explains this random motion using atomic theory

Opposition to the Atomic Theory

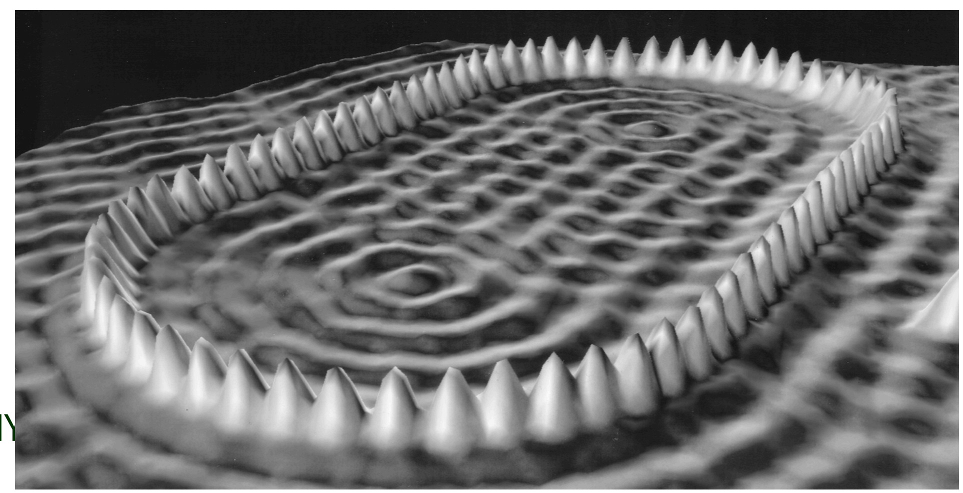
- Ernst Mach (1838 – 1916) opposes the theory on the basis of logical positivism, i.e., atoms being *"unseen" place into question their reality*
- Wilhelm Ostwald (1853 – 1932) supports this premise but on experimental results of radioactivity, discrete spectral lines, and the formation of molecular structures

Overwhelming Evidence for Existence of Atoms

- Max Planck (1858 – 1947) advances the concept to explain blackbody radiation by use of submicroscopic "quanta"
- Boltzmann requires existence of atoms for his advances in statistical mechanics
- Albert Einstein (1879 – 1955) uses molecules to explain Brownian motion and determines the approximate value of their size and mass
- Jean Perrin (1870 – 1942) experimentally verifies Einstein's predictions

Unresolved Questions and New Horizons

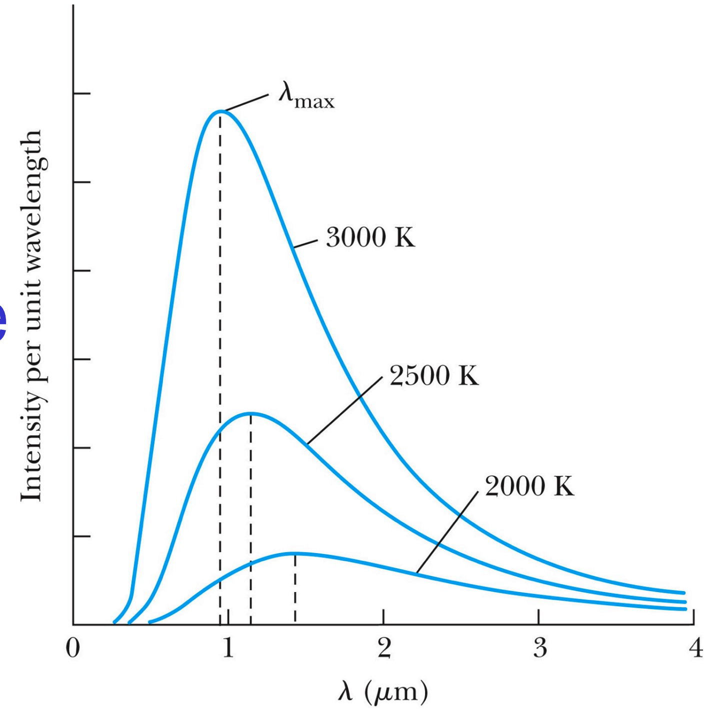
- The atomic theory controversy raises fundamental questions
  - It was not universally accepted
  - The constitutes (if any) of atoms became a significant question
  - The structure of matter remained unknown with certainty
  - Experimental precisions were insufficient to discern this level of small scale



Further Complications

Three fundamental problems:

- The (non) existence of an EM medium that transmits light from the sun
- The observed differences in the electric and magnetic field between stationary and moving reference systems
- The failure of classical physics to explain blackbody radiation in which characteristic spectra of radiation that cover the entire EM wavelengths were observed depending on temperature not on the body itself



Additional Discoveries Contribute to the Complications

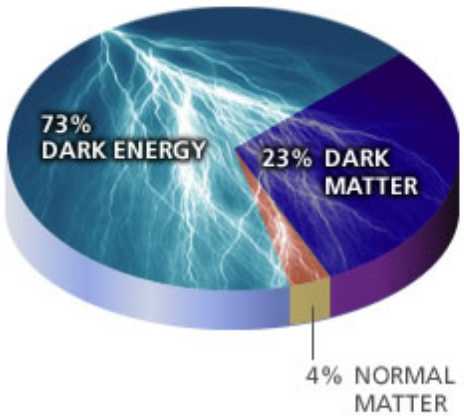
- Discovery of x-rays (1895, Rontgen)
- Discovery of radioactivity (1896, Becquerel)
- Discovery of the electron (1897, Thompson)
- Discovery of the Zeeman effect (1896, Zeeman) dependence of spectral frequency on magnetic field

The Beginnings of Modern Physics

- These new discoveries and the many resulting complications required a revision of the fundamental physical assumptions culminated in the successes of the classical foundations
- To this end the introduction of the modern theory of relativity and quantum mechanics becomes the starting point of this most fascinating revision

Unsolved Problems Today!

- Why are there three families of quarks and leptons?
- Why is the mass range so large ($0.1m_p$ – 175 m_p)?
- How do matters acquire mass?
  - Higgs mechanism but where is the Higgs, the God particle?
- Why is the matter in the universe made only of particles?
  - What happened to anti-particles? Or anti-matters?
- Do neutrinos have mass& what are the mixing parameters?
- Why are there only three apparent forces?
- Is the picture we present the real thing?
  - What makes up the 96% of the universe?
  - How about extra-dimensions?



- How is the universe created?
- Are there any other theories that describe the universe better?
- Many more questions to be answered!!