PHYS 3313 – Section 001
Lecture #3

Wednesday, Sept. 4, 2013
Dr. Jaehoon Yu

- 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
- Unsolved Questions Today!

Announcements

- Class e-mail distribution list subscription:
  - 29/50 have subscribed to the list
  - Please subscribe to the list before 8pm tonight (see page 10 of the 8/28 lecture note!)
  - I will send out a test message to confirm the communication
  - Please reply only to ME not to the entire class!! Check the recipient before clicking the send button!!
- A faculty research expo-II today at 4pm, SH101

Physics Department
The University of Texas at Arlington

COLLOQUIUM

Physics Faculty Research Expo #2

Wednesday September 4, 2013
4:00p.m. Rm. 101SH

SPEAKERS:

Dr. Yue Deng
"Space Physics: Energy Input Uncertainty and Important Physical Processes in the Upper atmosphere"

Dr. Suresh Sharma
"Having fun with surface plasmon excitations and their use in the study of electro-optical materials"

Dr. Wei Chen
"Nanoparticles for cancer treatment and radiation detection."

Dr. Manfred Cuntz
"Research in Stellar and Planetary Astrophysics"

Dr. Qiming Zhang
"Searching for Affordable Solar-cell Materials: A Computational Study"

Dr. Andrew Brandt
"Tagging Higgses"

Refreshments will be served at 3:30p.m in room 106 A SH

...lso Pizza will be pr... of Physics Students (SPS)
- **at ... om 101SH**

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 #1 above in terms of the gravitational force in #2. (5 points)

- You must look up the mass of the proton, actual size of the U^{238} nucleus, etc, and clearly write them on your project report
- 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. 9!

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 now know that gas consists 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=6.023x10^{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

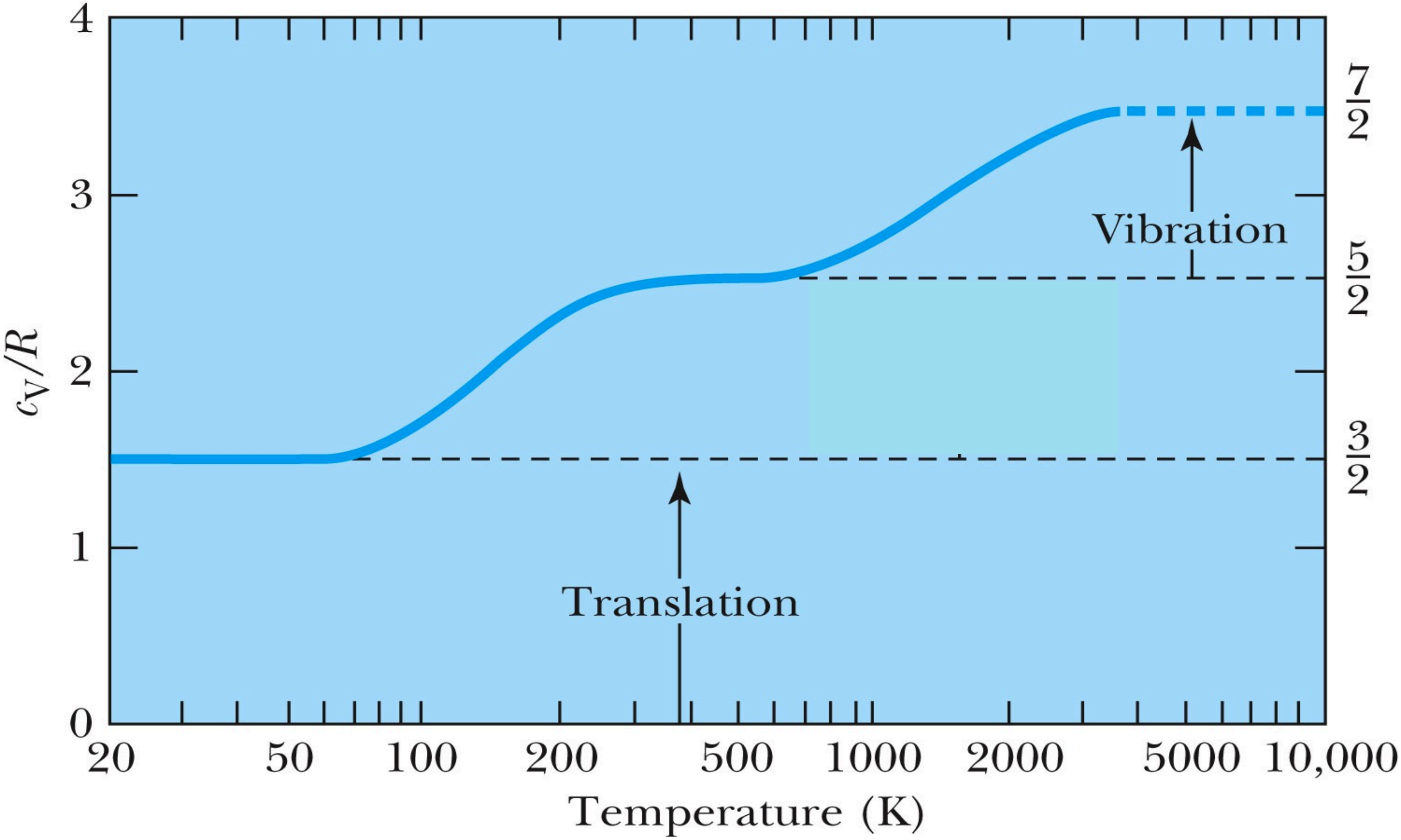
- Average molecular kinetic energy is directly related to absolute temperature
- **Internal energy** *U* is directly related to the average molecular kinetic energy
- Internal energy is equally distributed among the number of degrees of freedom (f) of the system

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

(N_A = Avogadro's Number)

- And many others

Experimental Demonstration of Equi-partition Principle



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

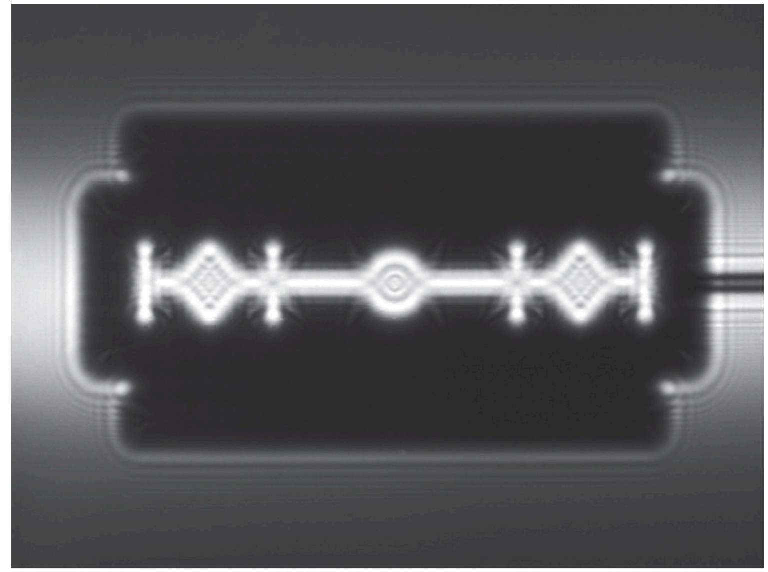
- Two distinct phenomena describing physical interactions
  - Both required Newtonian mass
  - Particles in the form of point masses and waves in the form of perturbation in a mass distribution, i.e., a material medium
  - The distinctions are observationally quite clear
    - However, not so obvious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

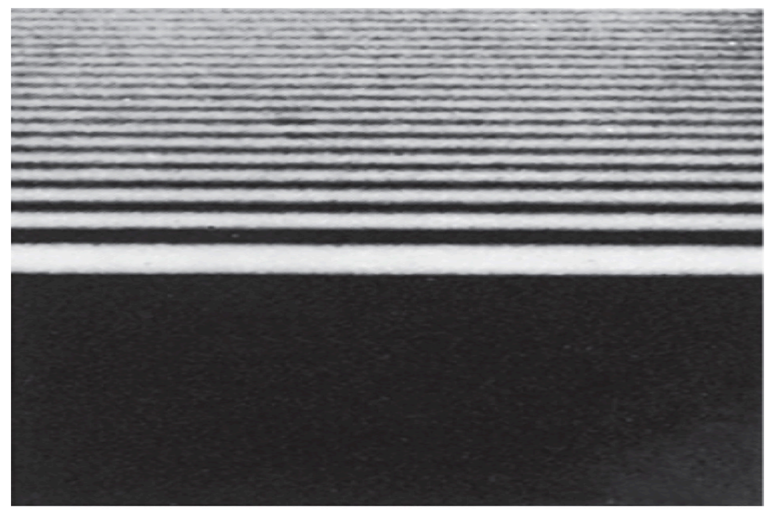
The Nature of Light

- 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 the theory in 1678
  - Light propagates as a wave of concentric circles from the point of origin
  - Explained reflection and refraction
  - Could not explain "sharp" edges of the shadow
- 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 water than air, 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 the 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 vacuum with the 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 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 (unified at high energies)**
    - **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 in the distance less than ~10^{-15} m

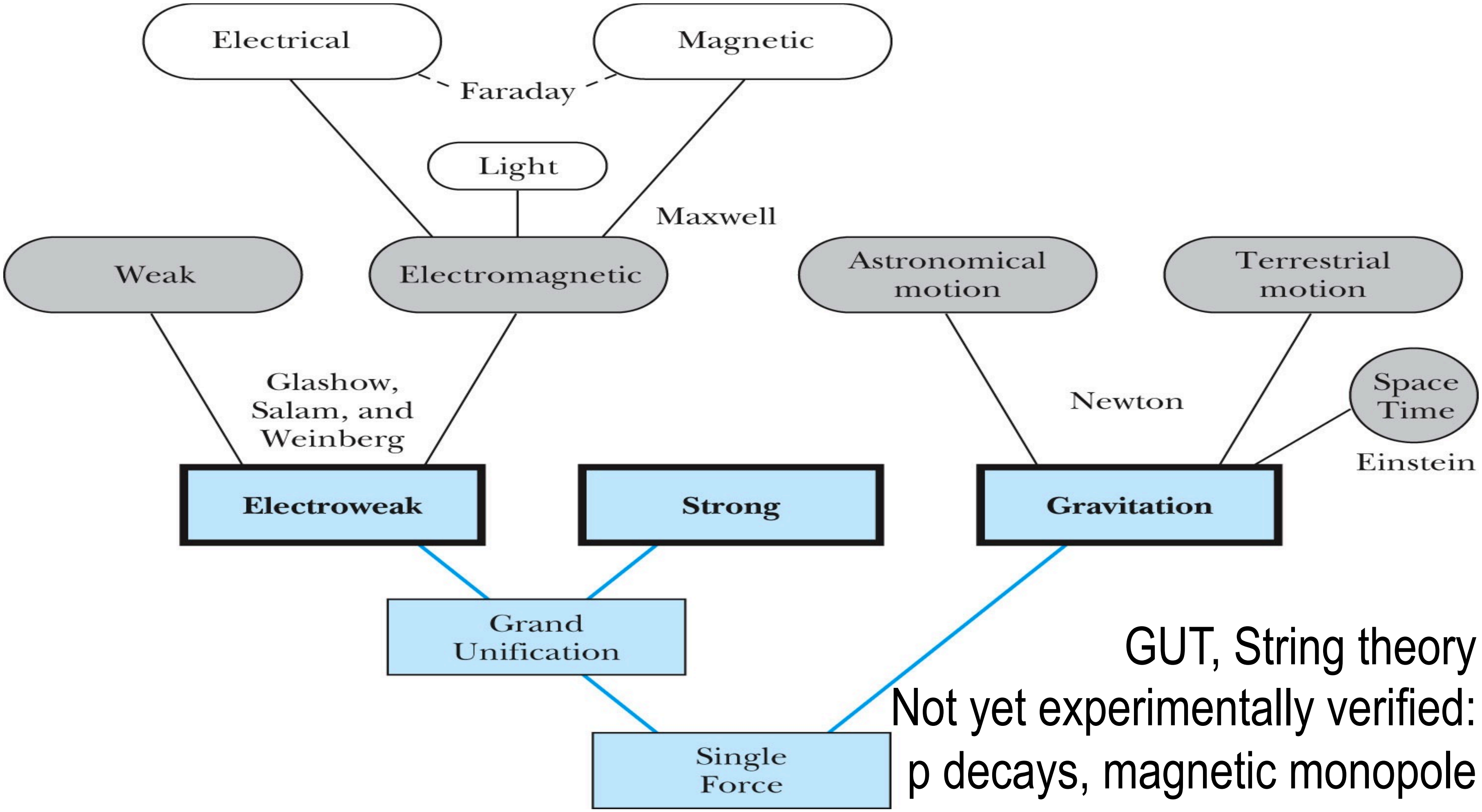
Relative Strength of Fundamental Forces

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.

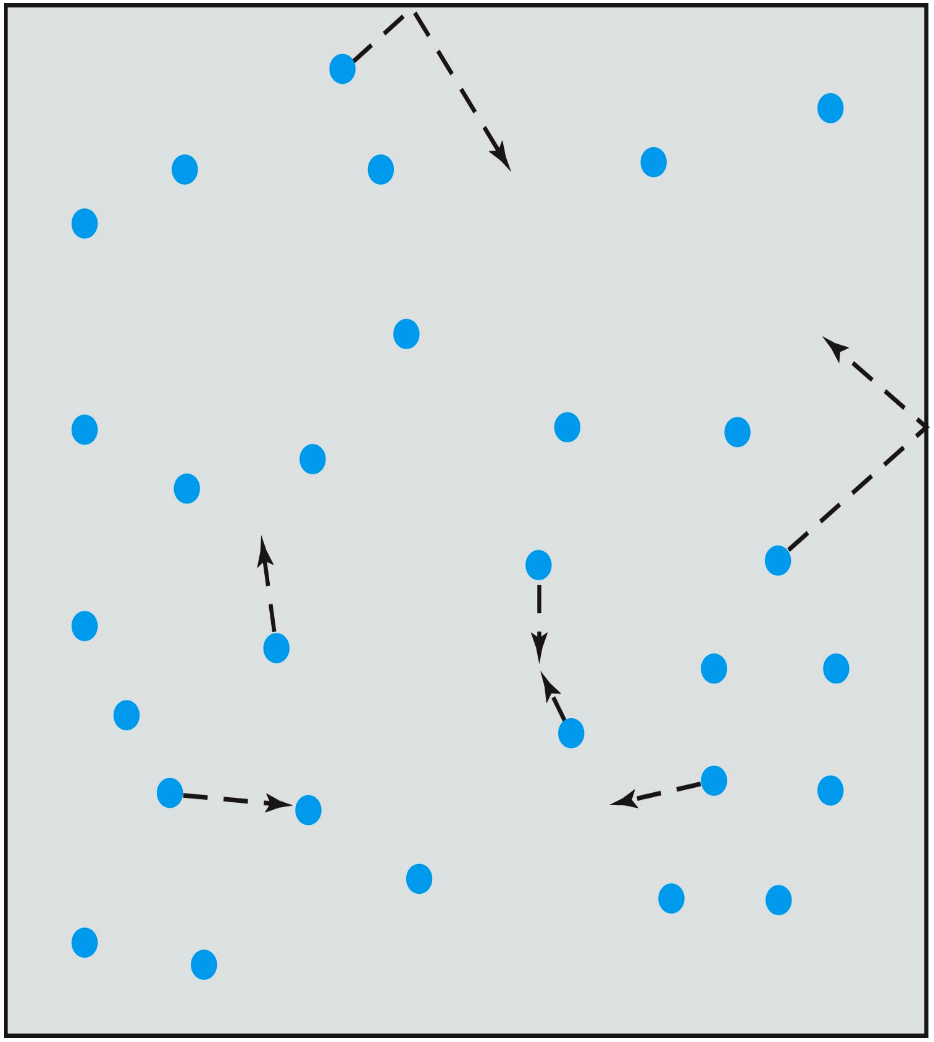
Unification of Forces



GUT, String theory
Not yet experimentally verified:
p decays, magnetic monopole

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 makes up matter



The Atomic Theory of Matter

- Concept initiated by Democritus and Leucippus (~450 B.C.) (first to use 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 proposed 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 (Brownian motion)
- Einstein in the 20^{th} century explains this random motion using atomic theory

Opposition to the Atomic Theory

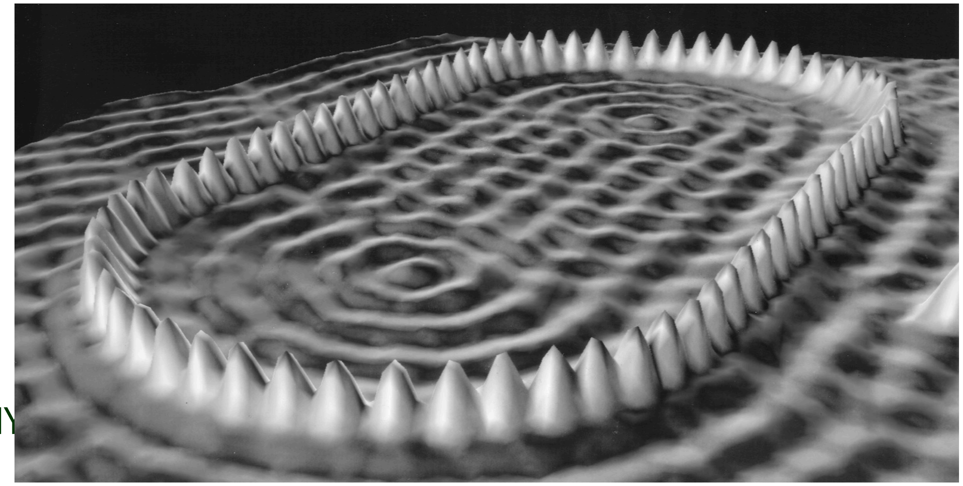
- Ernst Mach (1838 – 1916) opposes the theory on the basis of logical positivism, i.e., atoms being *"unseen" questions their reality*
- Wilhelm Ostwald (1853 – 1932) supports this premise but on experimental results of radioactivity, discrete spectral lines, and the formation of molecular structures

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 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

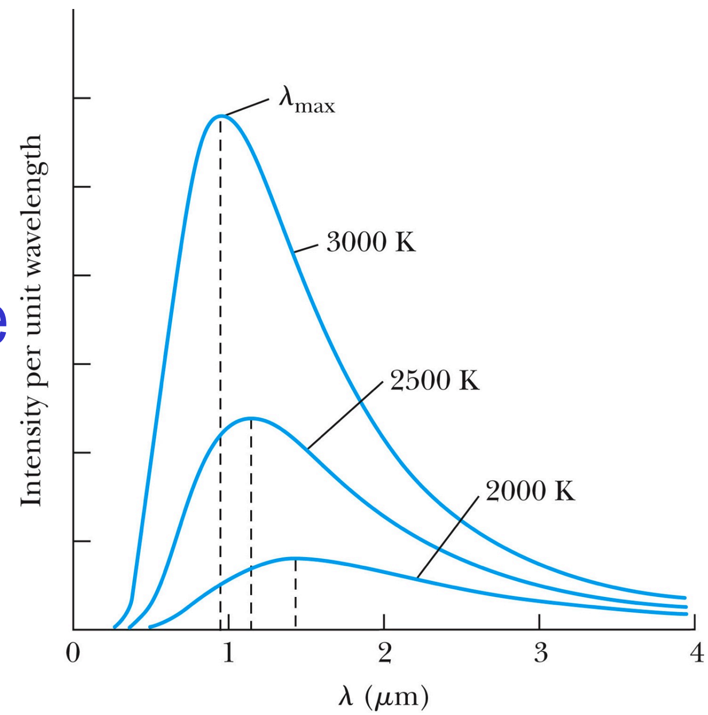
- The atomic theory controversy raises fundamental questions
  - It was not universally accepted
  - The constituents (if any) of atoms became a significant question
  - The structure of matter remained unknown with certainty
  - Experimental precisions were insufficient to discern this level of small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



Further Complications

Three fundamental problems:

- The (non) existence of a medium that transmits light waves 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?
  - Is the new particle we've discovered the Higgs 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!!