PHYS 3313 – Section 001
Lecture #3

Wednesday, Jan. 22, 2014

Dr. Jaehoon Yu

- Atomic Theory of Matter
- Unsolved Questions of 1895 and New Horizon
- Unsolved Questions Today!
- Galilean Transformation
- Do we need Ether?
- Michelson-Morley Experiment
- Einstein's postulates

Announcements

- Reading assignments: CH 2.10 (special topic), 2.13 and 2.14
  - Please go through eq. 2.45 through eq. 2.49 and example 2.9
- Homework #1
  - chapter 2 end of the chapter problems
  - 17, 21, 23, 24, 32, 59, 61, 66, 68, 81 and 96
  - Due is by the beginning of the class, Monday, Feb. 3
  - Work in study groups together with other students but PLEASE do write your answer in your own way!
- Colloquium today
  - Dr. Patrick Dholabhai, Los Alamos National Laboratory

Fundamentals of Energy Materials: A Theoretical Perspective

Pratik P. Dholabhai
Materials Science & Technology Division
Los Alamos National Laboratory

Recent advances in theory have enabled understanding of material behavior and prediction of diverse properties of materials well in advance before synthesis in a laboratory. Some key examples of how we have effectively utilized various theoretical approaches to elucidate the fundamental physics and chemistry of materials used in advanced energy applications will be presented. The talk will describe our approach to three relevant systems – (i) Blend of atomistic calculations and first principles calculations to comprehend radiation damage evolution in oxide ceramic nanocomposites used in nuclear energy technology (ii) First principles computations used in conjunction with kinetic lattice Monte Carlo simulations to predict novel ceria-based electrolyte materials used in intermediate-temperature solid oxide fuel cells (iii) Electronic structure calculations used in combination with time-dependent quantum wave packet dynamics model to appreciate the fundamental photochemistry observed on titania-based photocatalysts used in solar cells. In the above examples, pertinent experimental data will be presented as work was performed in parallel with experimental efforts.

Acknowledgements: Work supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences.

Reminder: 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)

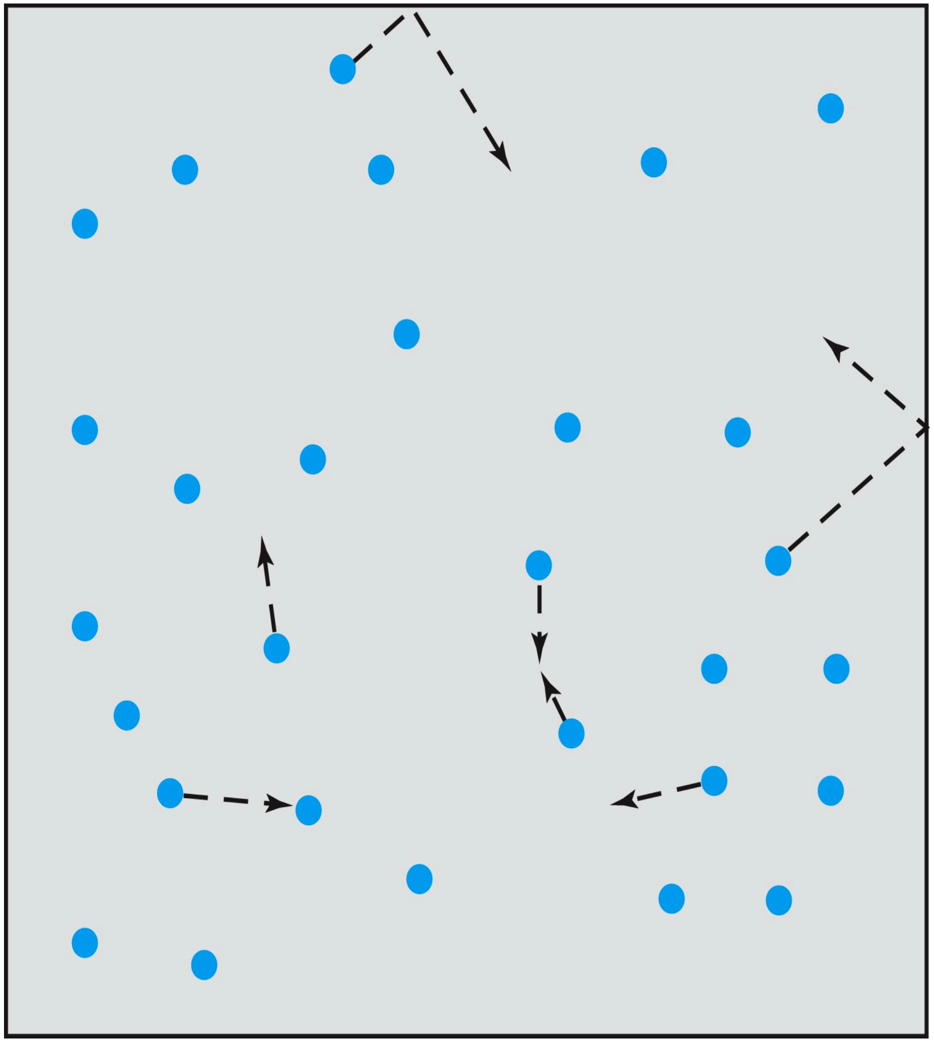
- You must look up the mass of the proton, actual size of the U^{238} nucleus, etc, and clearly write them on your project report
- You MUST have your own, independent answers to the above three questions even if you worked together with others. All those who share the answers will get 0 credit if copied.
- Due for the submission is Monday, Jan. 27!

Group, Topic & Presentation Association

Research Group	Research Topic	Presentation Date and Order
1	7	4/30 – 2
2	3	4/28 – 3
3	2	4/30 – 4
4	4	4/28 – 2
5	1	4/28 – 4
6	8	4/28 – 1
7	5	4/30 – 1
8	6	4/30 – 3

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**➔ A compound of 2 or more elements, the weight proportion of the elements is always same
- 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 a 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 20th century explains this random motion using atomic theory

Opposition to the Atomic Theory

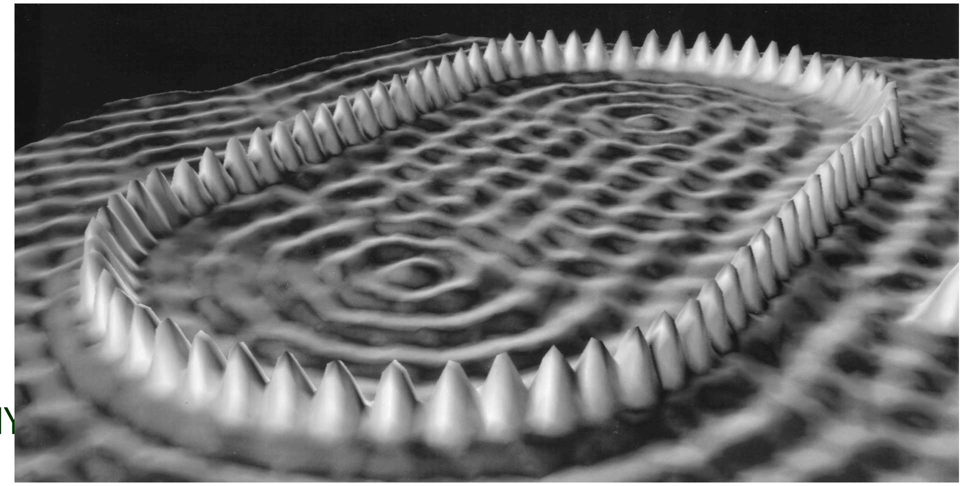
- Ernst Mach (1838 – 1916) opposes the theory on the basis of logical positivism, i.e., atoms being *“unseen” questions their reality*
- Wilhelm Ostwald (1853 – 1932) supports this premise and called atoms hypothetical structures for bookkeeping based on experimental results of radioactivity, discrete 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, using 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

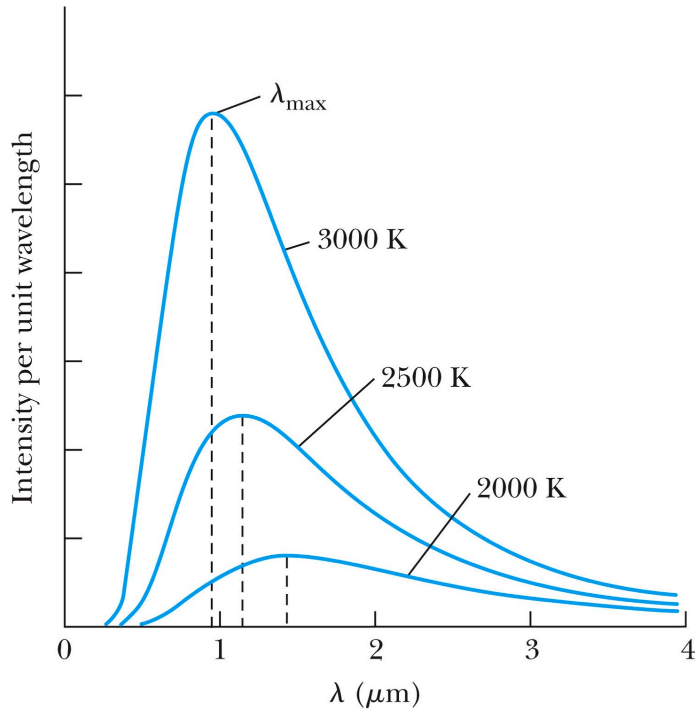
- The atomic theory controversy raises fundamental questions
  - It was not universally accepted
  - The constituents (if any) of atoms became a significant question
  - The structure of matter remained unknown with certainty
  - Experimental precisions were insufficient to discern this level of small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

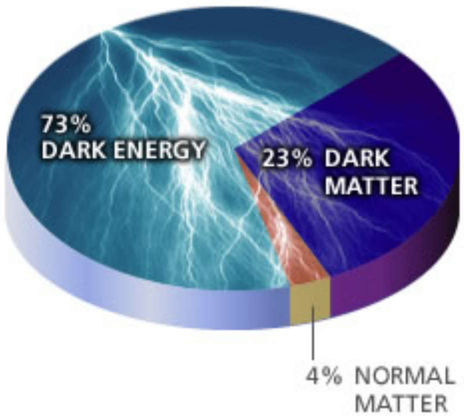
- Discovery of x-rays (1895, Rontgen)
- Discovery of radioactivity (1896, Becquerel)
- Discovery of the electron (1897, Thompson)
- Discovery of the Zeeman effect (1896, Zeeman) dependence of spectral frequency on magnetic field

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?

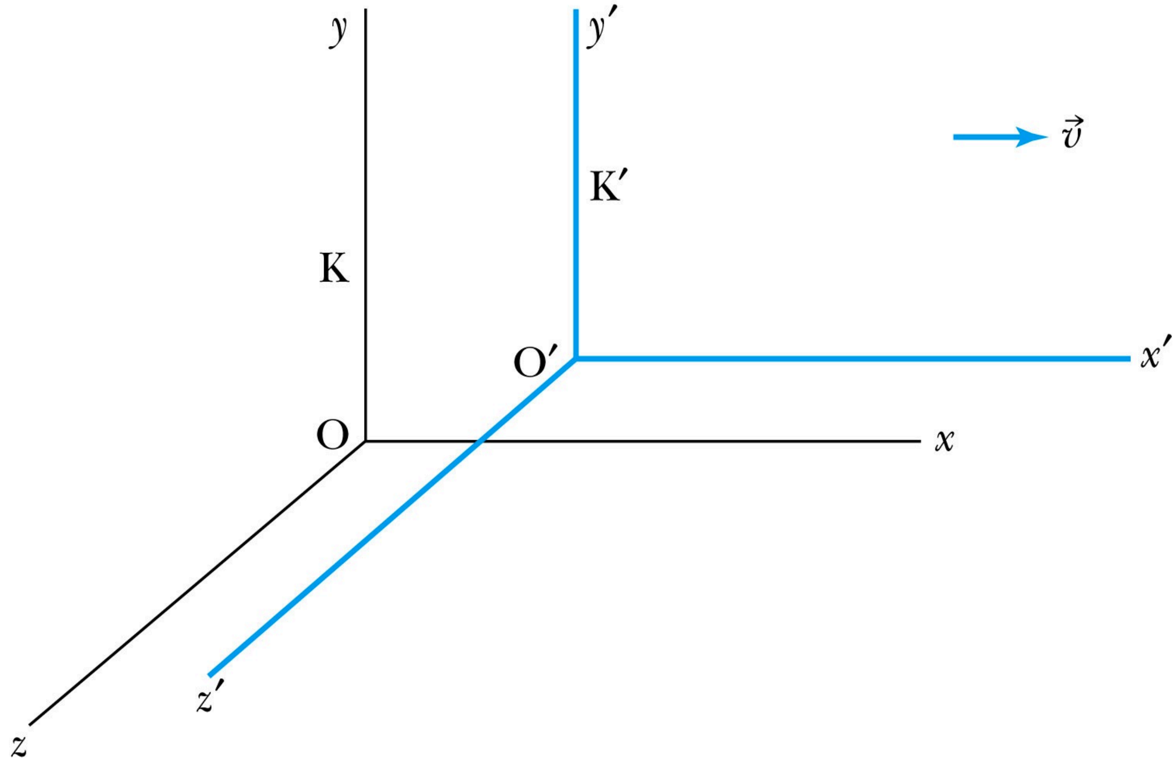


- How is the universe created?
- Are there any other theories that describe the universe better?
- Many more questions to be answered!!

Newtonian (Classical) Relativity

- It is assumed that Newton's laws of motion must be measured with respect to (relative to) some reference frame.
- A reference frame is called an **inertial frame** if Newton laws are valid in that frame.
- Such a frame is established when a body, not subjected to net external forces, is observed to move in rectilinear motion at constant velocity
- ➔ Newtonian Principle of Relativity (Galilean Invariance): If Newton's laws are valid in one reference frame, then they are also valid in another reference frame moving at a uniform velocity relative to the first system.

Inertial Frames K and K'

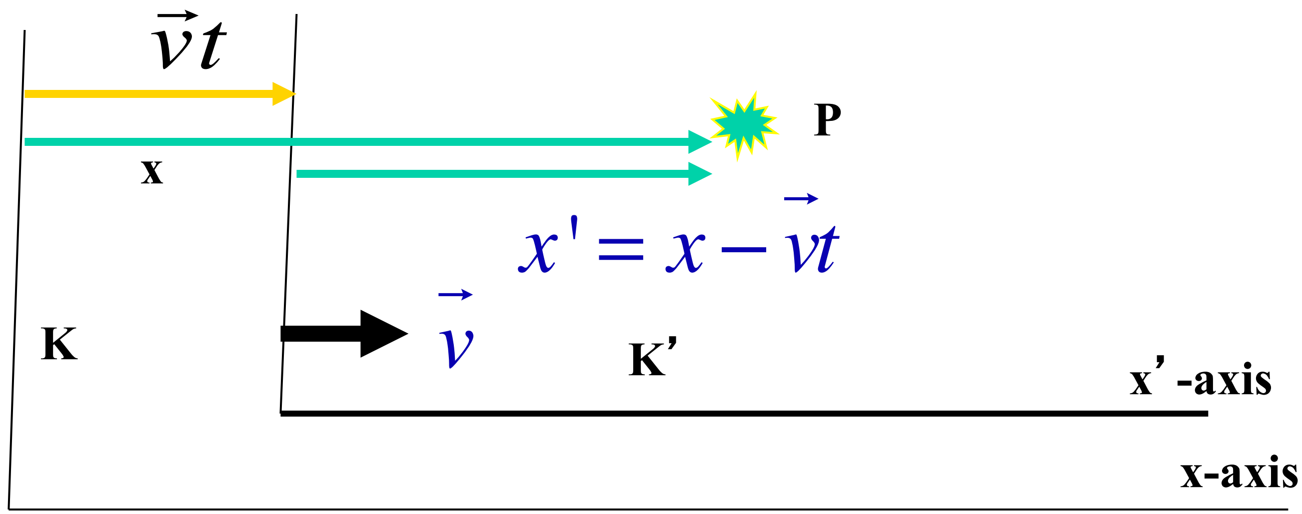


- K is at rest and K' is moving with a constant velocity $\vec{v}$
- Axes are parallel
- K and K' are said to be *INERTIAL COORDINATE SYSTEMS*

The Galilean Transformation

For a point P

- In system K: P = (x, y, z, t)
- In system K' : P = (x' , y' , z' , t')



Conditions of the Galilean Transformation

- Parallel axes between the two inertial reference frames
- K' has a constant relative velocity in the *x*-direction with respect to K

$$x' = x - \vec{v}t$$

$$y' = y$$

$$z' = z$$

$$t' = t$$

- **Time** (*t*) for all observers is a *Fundamental invariant*, i.e., the same for all inertial observers
  - Space and time are separate!!

The Inverse Relations

Step 1. Replace $\vec{v}$ with $-\vec{v}$

Step 2. Replace "primed" quantities with "unprimed" and "unprimed" with "primed"

$$x = x' + \vec{v}t$$

$$y = y'$$

$$z = z'$$

$$t = t'$$