PHYS 3313 – Section 001
Lecture #2

Wednesday, Jan. 15, 2014
Dr. Jaehoon Yu

- What do you expect to learn in this course?
- 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
- Unsolved Questions Today!

Announcements

- Reading assignment #1:
  – Review Appendices 1, 2 and 9
  – Read and follow through Appendices 3, 5, 6 and 7 by Tuesday, Jan. 21, 2014
  – There will be a quiz next Wednesday, Jan. 22, on this reading assignment

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!

In this course, you will learn…

- Concepts and derivation of many of the modern physics
  - Special relativity
  - Quantum theory
  - Atomic physics
  - Condensed Matter physics
  - Nuclear physics
  - Particle Physics
- Focus on learning about the concepts with less complicated math
- You will be able to understand what fundamental physics provides bases for the current technology

Research Topics

1. Black body radiation
2. Michelson–Morley Experiment
3. The Photoelectric Effect
4. The Property of Molecules, Brownian Motion
5. Compton Effect
6. Discovery of Electron
7. Rutherford Scattering
8. Super-conductivity

Group – Research Topic Association

Research Group Number	Research Topic
1	7
2	3
3	2
4	4
5	1
6	8
7	5
8	6

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

$\Rightarrow$ Theory and Experiment work hand-in-hand

$\Rightarrow$ Theory works generally under restricted conditions

$\Rightarrow$ Discrepancies between experimental measurements and theory are good for improvements

$\Rightarrow$ 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, concepts of many kinematic parameters, including forces
    - First unification of forces – planetary forces and forces on the Earth
- AD 19th Century:
  - Electricity, Magnetism, and Thermodynamics
- Late AD 19th and early 20th century (Modern Physics Era, after 1895)
  - Physicists thought everything was done and nothing new could be discovered

State of Minds in late 19th Century

- **Albert A. Michelson, 1894**

  The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote. Our future discoveries must be looked for in the sixth place of decimals!

- **William Thompson (Lord Kelvin), 1900**

  There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.

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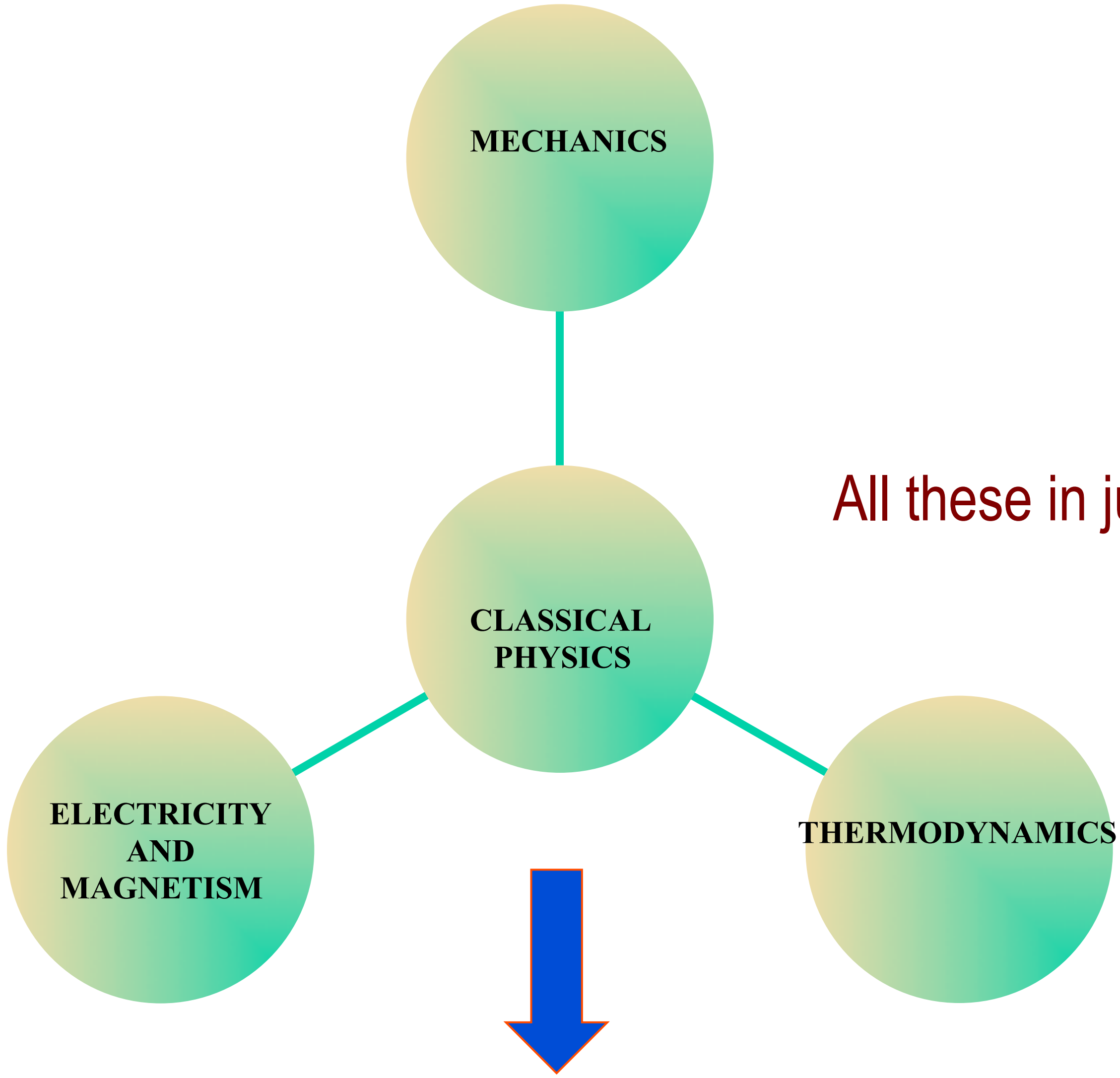
  - Physicists thought everything was done and nothing new could be discovered
  - Concept of atoms did not quite exist
  - There were only handful of problems not well understood late 19th century became the basis for new discoveries in 20th century
  - That culminates in understanding of phenomena in 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



All these in just 200 years!!

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, concept of forces ➔ First unification of forces!!

- **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**):
- $\vec{F} = m\vec{a}$ **or** $\vec{F} = \frac{d\vec{p}}{dt}$
- **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)

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 ($N_A = 6.023 \times 10^{23}$ 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

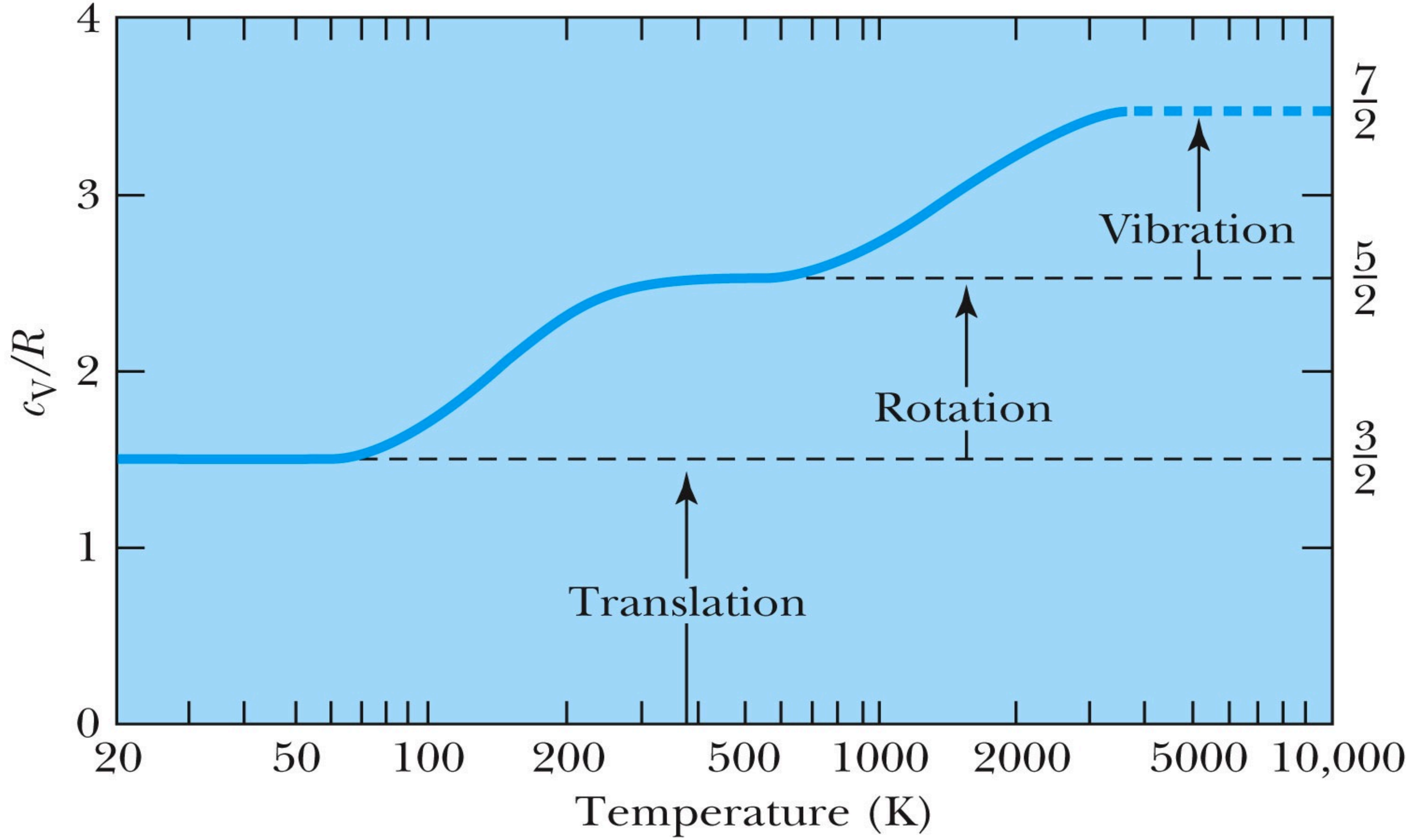
- Average molecular kinetic energy is directly related to absolute temperature
- **Internal energy** *U* is directly related to the average molecular kinetic energy
- Internal energy is equally distributed among the number of degrees of freedom (f) of the system

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

(N_A = Avogadro's Number)

- And many others

Experimental Demonstration of Equipartition 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

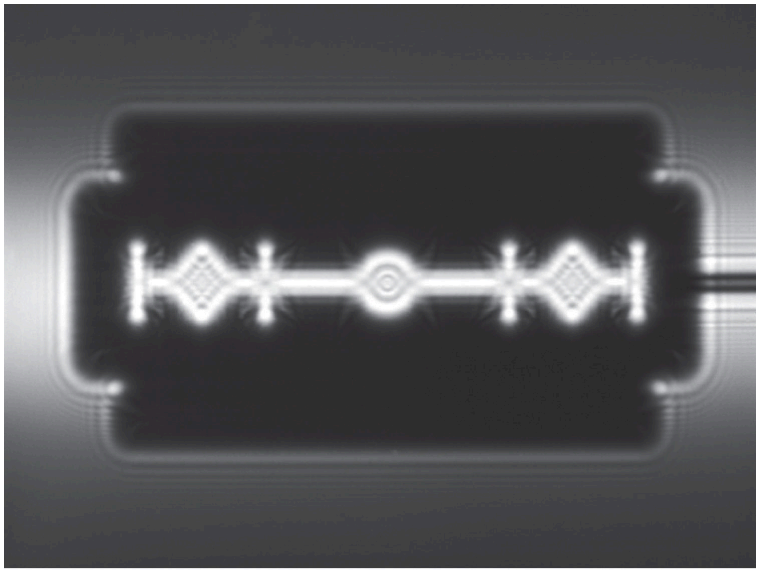
- Two distinct phenomena describing physical interactions
  - Both required Newtonian mass
  - Particles in the form of point masses and waves in the form of perturbation in a mass distribution, i.e., a material medium
  - The distinctions are observationally quite clear
    - However, not so obvious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

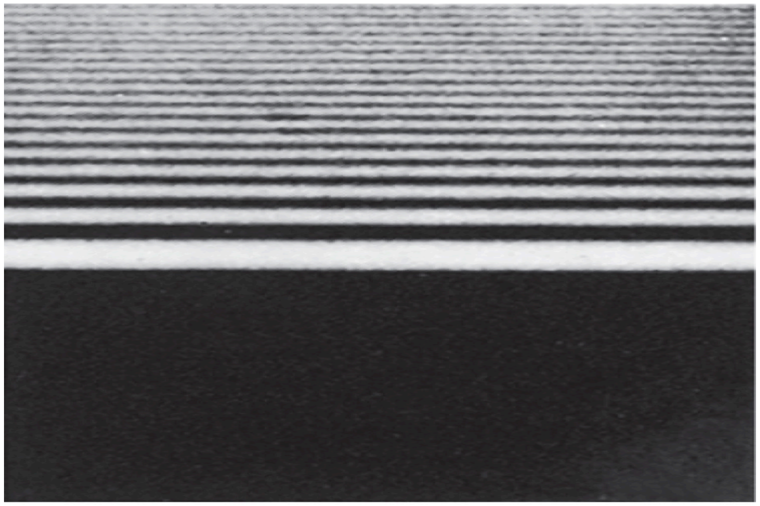
The Nature of Light

- 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

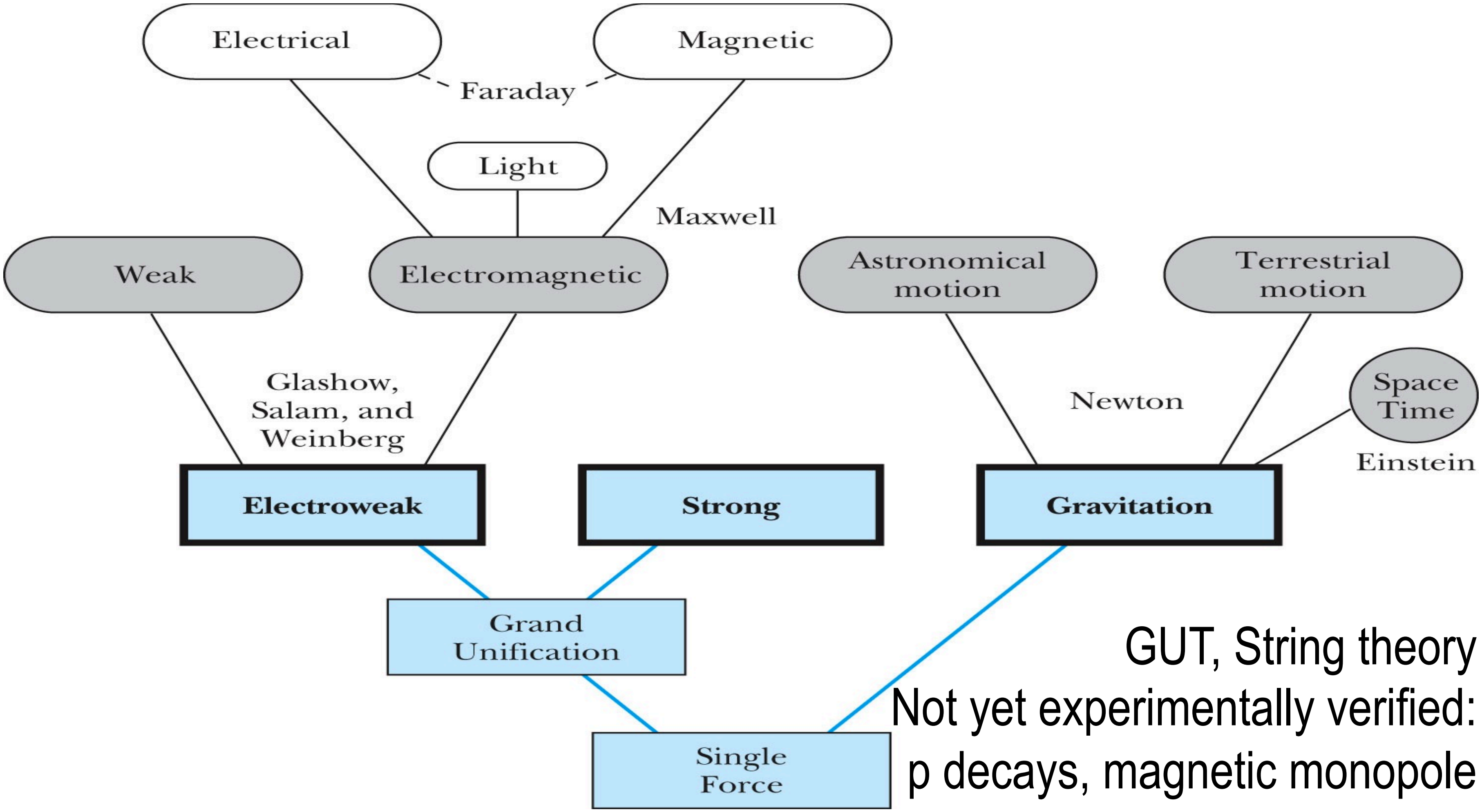
Relative Strength of Fundamental Forces

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