PHYS 3313 – Section 001
Lecture #3

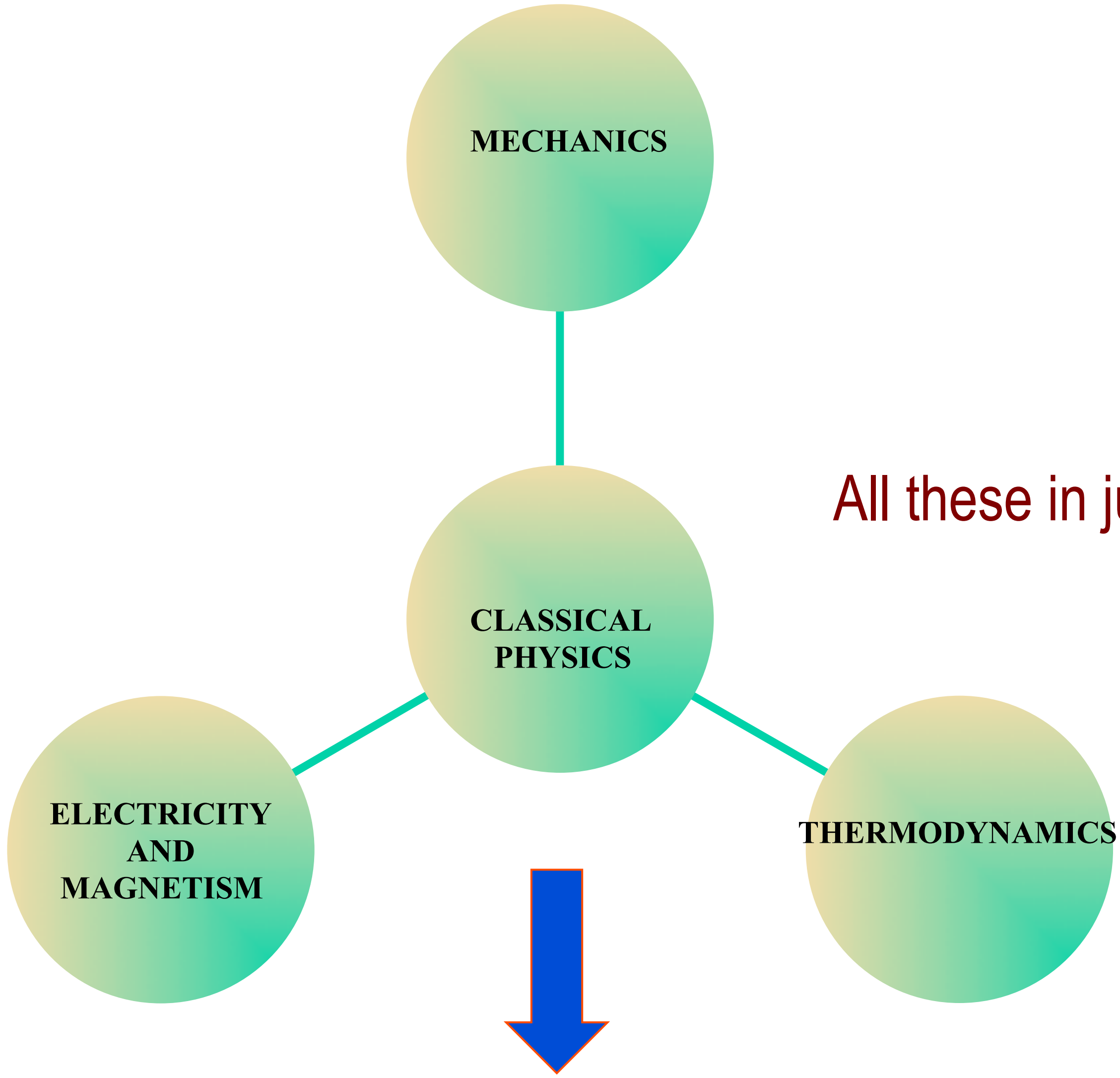
Wednesday, Jan. 28, 2015
Dr. Jaehoon Yu

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

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, Feb. 2!



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 wall!!

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 ($N_A=6.023\times10^{23}$ 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 19th century

Primary Results of Statistical Interpretation

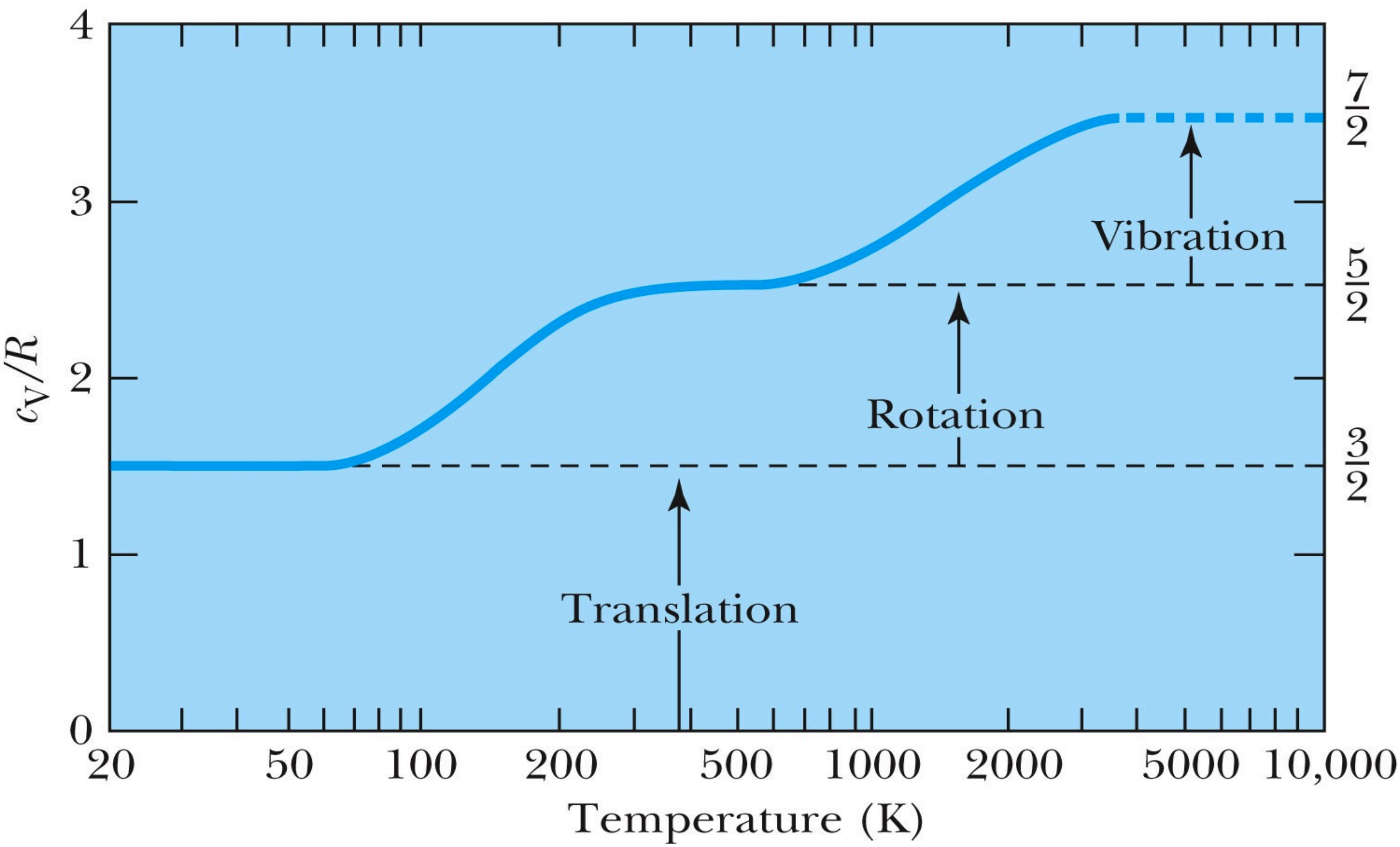
- Average molecular kinetic energy is directly related to the absolute temperature
- **Internal energy** *U* is directly related to the average molecular kinetic energy
- Internal energy is equally distributed among the number of degrees of freedom (f) of the system

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

(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

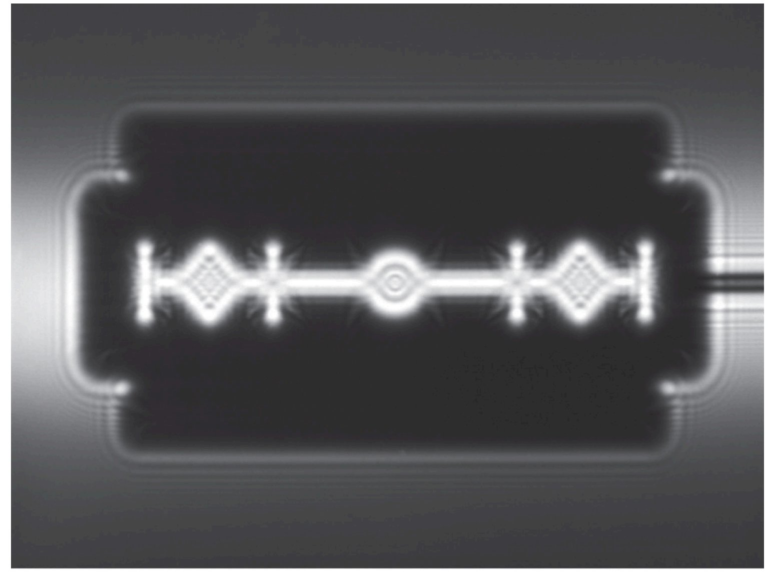
- Two distinct phenomena describing physical interactions
  - Both required Newtonian mass
  - Particles in the form of point masses and waves in the form of perturbation in a mass distribution, i.e., a material medium
  - The distinctions are observationally quite clear
    - However, not so obvious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

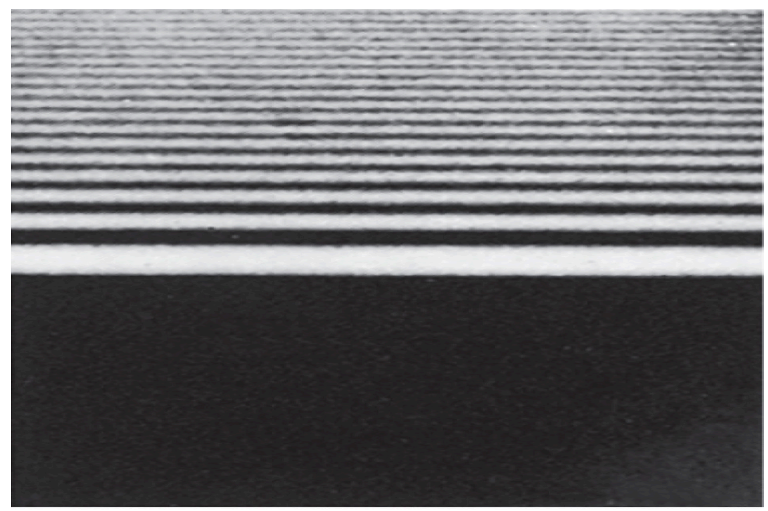
The Nature of Light

- 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

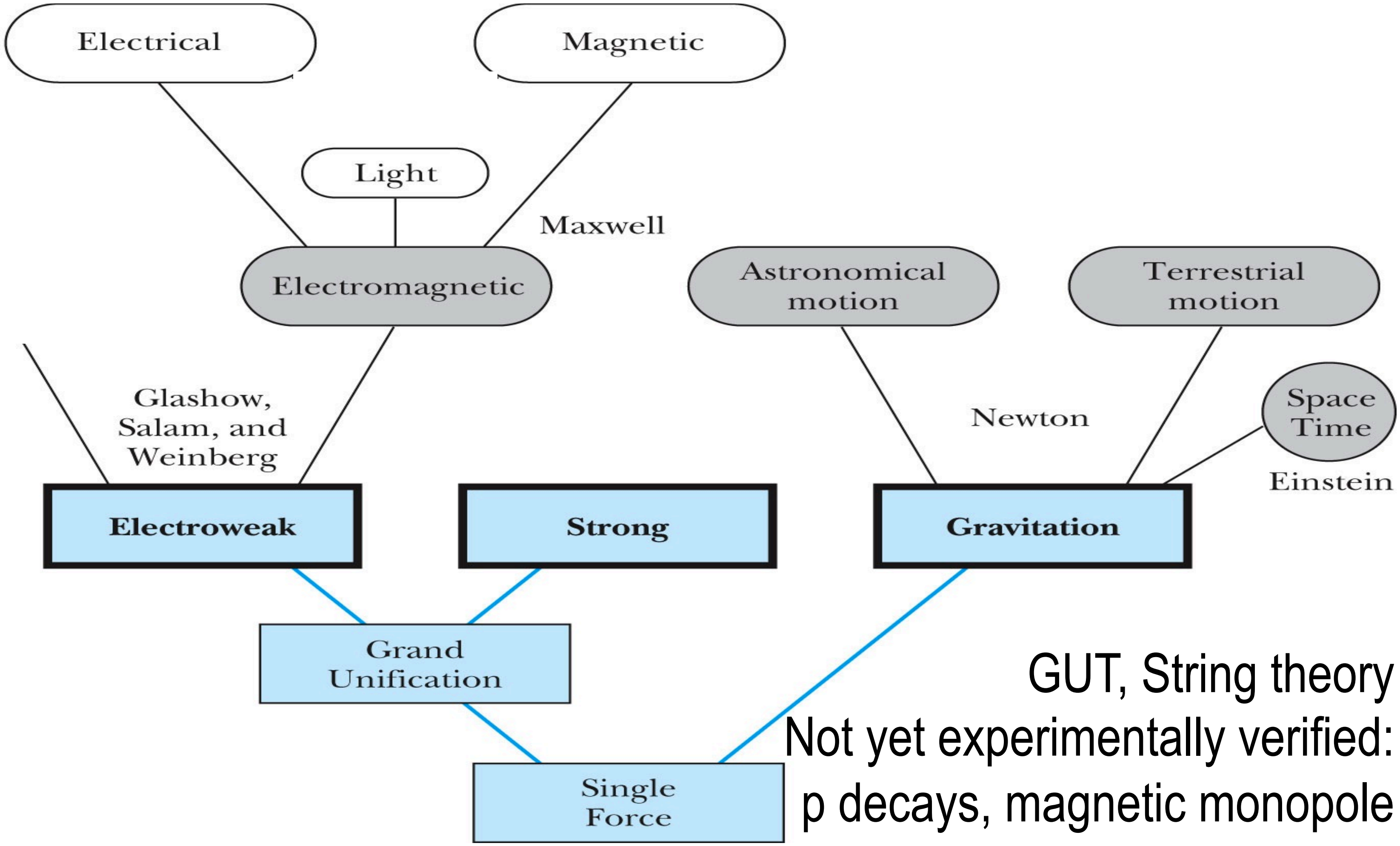
Relative Strength of Fundamental Forces

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