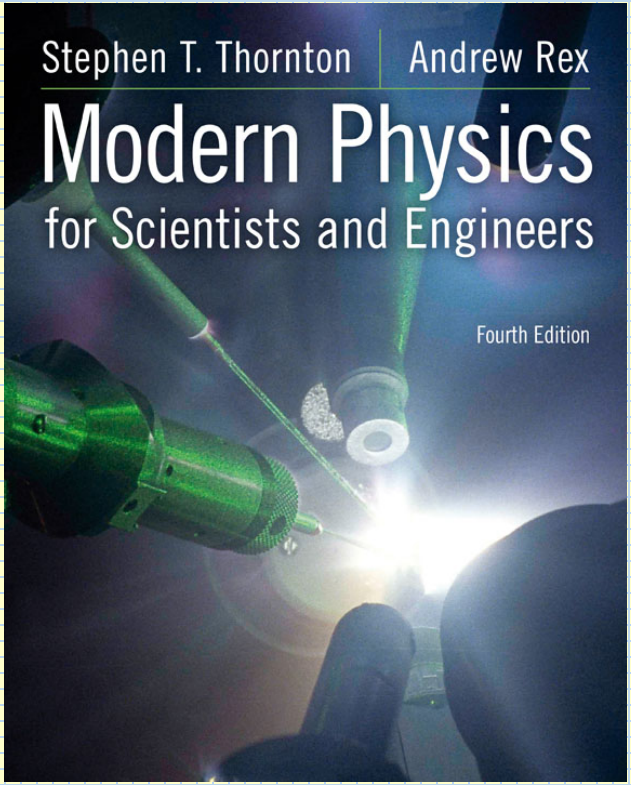
Modern Physics for Scientists and Engineers

Thornton & Rex, 4th ed.



CHAPTER 1

The Birth of Modern Physics

Topics

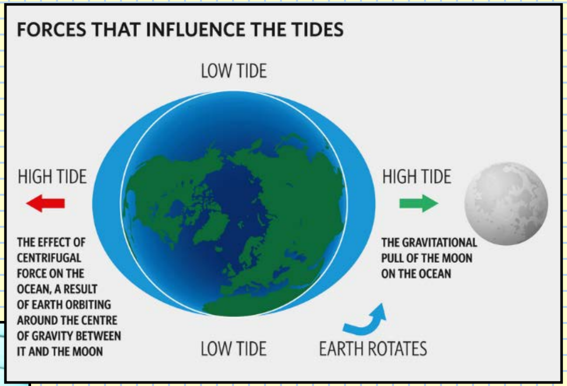
1) Classical Physics of the 1890s
2) Kinetic Theory of Gases
3) Atomistic Theory of Matter
4) Mechanical Waves
5) A Few Dark Clouds

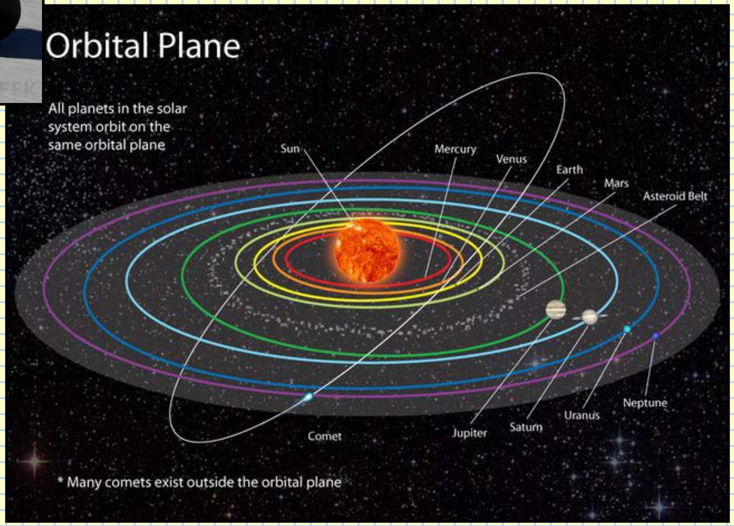
1) Classical Physics of the 1890s

- **Mechanics**
- **Electromagnetism**
- **Thermodynamics**

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. - Albert A. Michelson, 1894

Mechanics

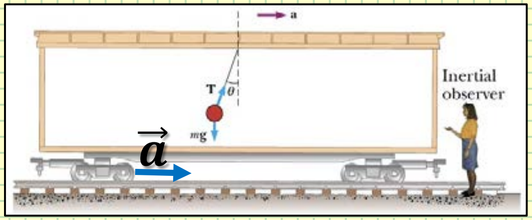

FORCES THAT INFLUENCE THE TIDES
LOW TIDE
HIGH TIDE
HIGH TIDE
THE EFFECT OF CENTRIFUGAL FORCE ON THE OCEAN, A RESULT OF EARTH ORBITING AROUND THE CENTRE OF GRAVITY BETWEEN IT AND THE MOON
THE GRAVITATIONAL PULL OF THE MOON ON THE OCEAN
LOW TIDE
EARTH ROTATES

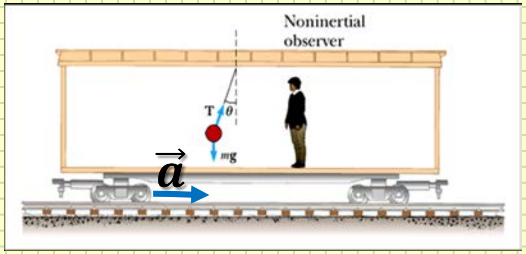

Orbital Plane
All planets in the solar system orbit on the same orbital plane
Sun
Mercury
Venus
Earth
Mars
Asteroid Belt
Neptune
Uranus
Saturn
Jupiter
Comet
* Many comets exist outside the orbital plane

Contributions from:

- Galileo Galilei
- Kepler
- Isaac Newton
- Euler
- Lagrange
- Hamilton

Newton's Laws



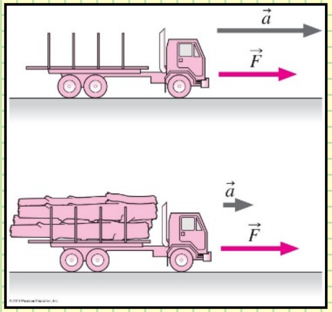


Newton's First Law:

$$\vec{F} = 0 \Leftrightarrow \vec{a} = 0$$

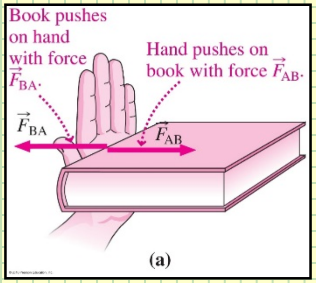
Newton's Second Law:

$$\vec{F} = m\,\vec{a}$$



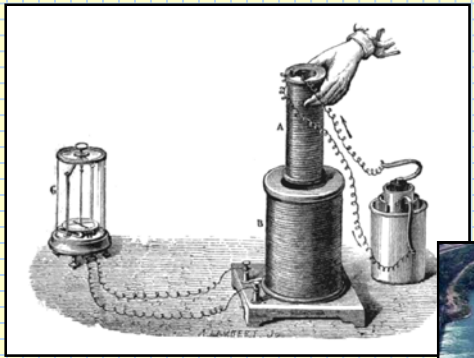
Newton's Third Law:

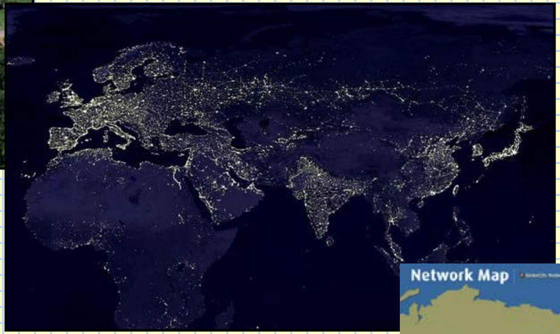
$$\vec{F}_{A\,B} = -\,\vec{F}_{B\,A}$$



Electricity and Magnetism

= Electromagnetism





Contributions from:

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

Maxwell's Equations and Lorentz Law

- **Gauss's law (Φ_E): (electric field)**

$$\oiint_S \vec{\boldsymbol{E}}(\boldsymbol{r}) \, . \, \boldsymbol{d}\vec{\boldsymbol{A}} = \sum_{i\,=\,inside} \frac{q_i}{\epsilon_0} = \frac{Q_{inside}}{\epsilon_0}$$

- **Gauss's law (Φ_B): (magnetic field)**

$$\oiint_S \vec{\boldsymbol{B}}(\boldsymbol{r}) \, . \, \boldsymbol{d}\vec{\boldsymbol{A}} = 0$$

- **Faraday's law:**

$$\oint_C \vec{\boldsymbol{E}}(\boldsymbol{r}) \, . \, \boldsymbol{d}\vec{\boldsymbol{s}} = -\frac{d\Phi_B}{dt}$$

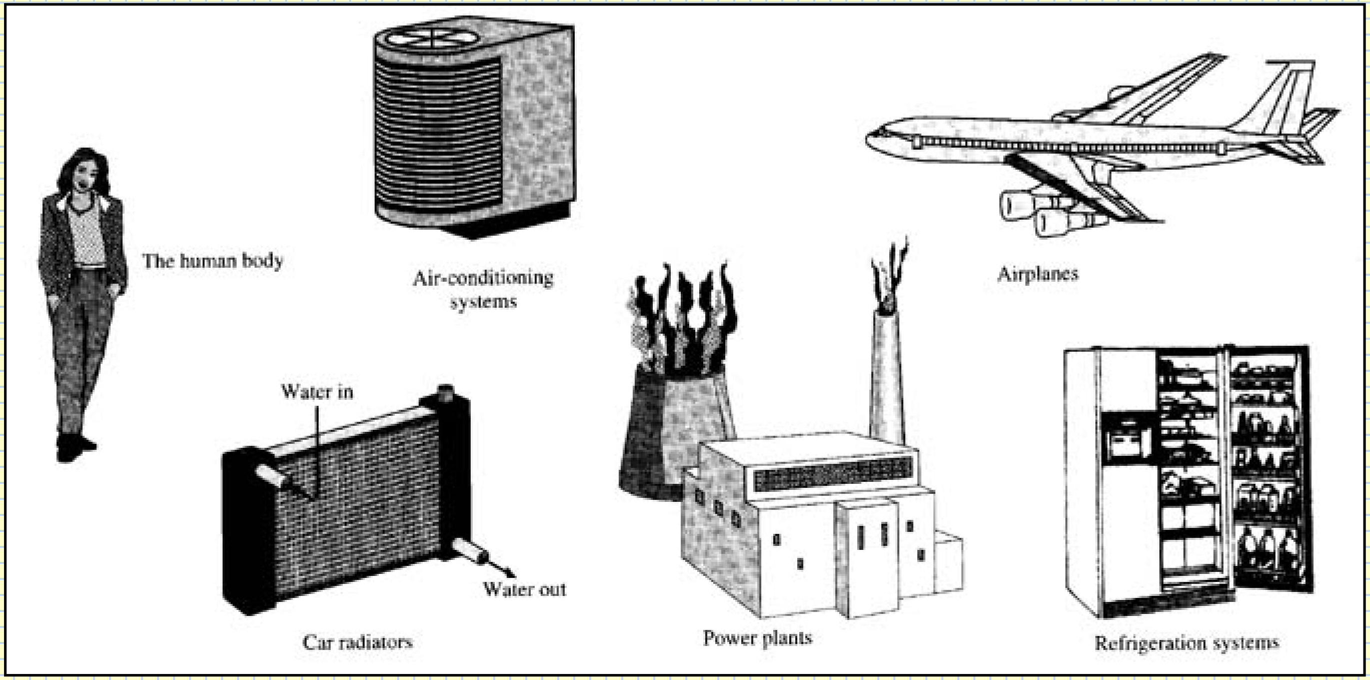
- **Ampère's law: (generalized)**

$$\oint_C \vec{\boldsymbol{B}}(\boldsymbol{r}) \, . \, \boldsymbol{d}\vec{\boldsymbol{s}} = \mu_o \, I + \mu_o \, \epsilon_o \frac{d\Phi_E}{dt}$$

- **Lorentz law: (force)**

$$\vec{\boldsymbol{F}} = q \, \vec{\boldsymbol{E}} + q \, \vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}}$$

Thermodynamics



Contributions from:

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

Key Concepts

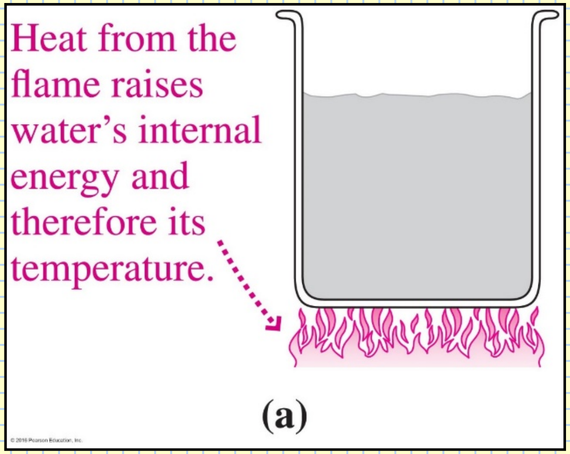
- Temperature, internal energy, heat, work, and entropy.
- Introduces the concept of internal energy.
- Temperature as a measure of internal energy.
- Establishes heat as energy transferred due to temperature difference.
- Thermal equilibrium: a state in which the macroscopic properties (p, V, and T) no longer change with time if the system is mechanically and thermally isolated.

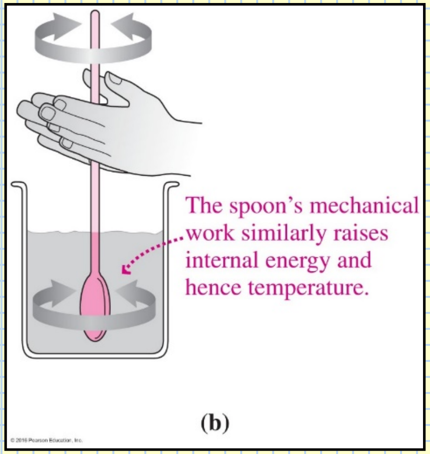
The Laws of Thermodynamics

- The "zeroth" law: two systems in thermal equilibrium with a third system are in thermal equilibrium with each other.

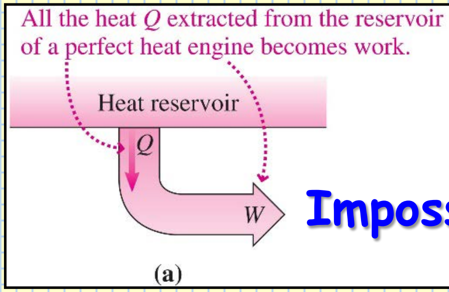
- First law: The change in the internal energy ΔU of a system is equal to the heat Q added to a system plus the work W done by the system

$$\Delta U = Q + W$$

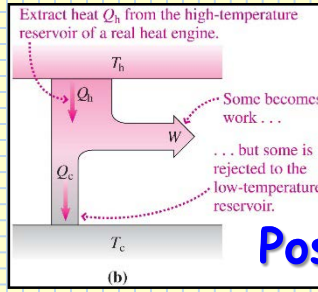




- **Second law (a): It is not possible to convert heat completely into work without some other change taking place.**



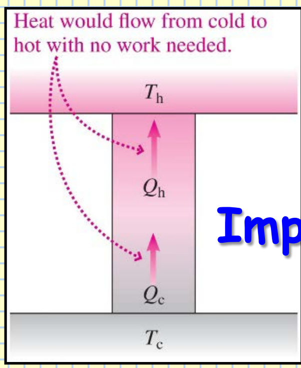
Impossible !!



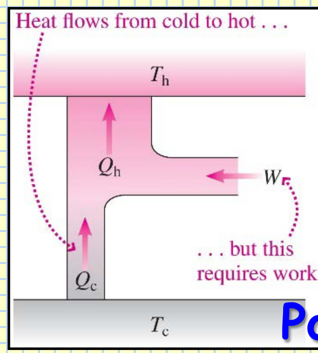
Possible !!

$$e \equiv \frac{W}{Q_h} = 1 - \frac{T_c}{T_h}$$

- **Second law (b): It is not possible to fully transfer heat from a cold to a hot reservoir without work.**



Impossible !!



Possible !!

- **Third law: It is not possible to achieve an absolute zero temperature ($T > 0\,K$).**

2) Kinetic Theory of Gases

Contributions made by:

- Robert Boyle (1627-1691)
- Jacques Charles (1746-1823)
- Joseph Louis Gay-Lussac (1778-1823)

Culminated in the ideal gas equation for n moles of a "simple" gas:

$$P\ V = n\ R\ T$$

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

Additional Contributions

- Amedeo Avogadro (1776-1856)
- John Dalton (1766-1844)
- Daniel Bernoulli (1700-1782)
- Ludwig Boltzmann (1844-1906)
- James Clerk Maxwell (1831-1879)
- J. Willard Gibbs (1939-1903)

Main Results

- **The average molecular kinetic energy is directly related to the absolute temperature:**

$$\langle K \rangle = \frac{3}{2} k\, T$$

- **The internal energy is equally distributed among all degrees of freedom (f) of the system:**

$$U = N \frac{f}{2} k\, T$$

- **The molar heat capacity at constant volume (c_V) is given by:**

$$c_v = \frac{\partial U}{\partial T} = \frac{f}{2} R$$

- **The molecular speed distribution $f(v)$ is described:**

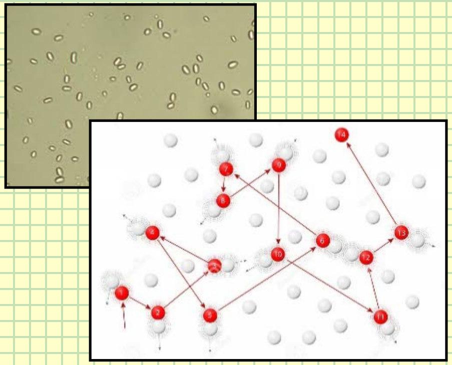
$$f(v) = 4\pi N \left(\frac{m}{2\pi kT} \right)^{3/2} v^2 e^{-mv^2/2kT}$$

$$v_{rms} = \sqrt{\langle v^2 \rangle} = \sqrt{\frac{3kT}{m}}$$

3) Atomistic Theory of Matter

Contributions from:

- **John Dalton** advances the atomic theory of matter to explain the law of definite proportions



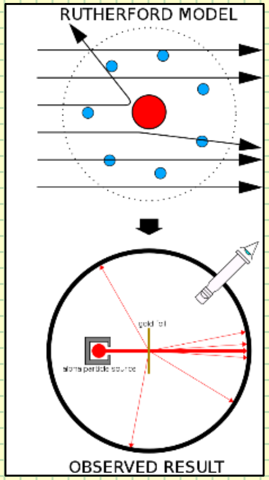
- **Robert Brown** observes microscopic "random" motion of suspended grains of pollen in water

- **Albert Einstein** (1879 – 1955) uses molecules to explain Brownian motion and determines the approximate value of their size and mass

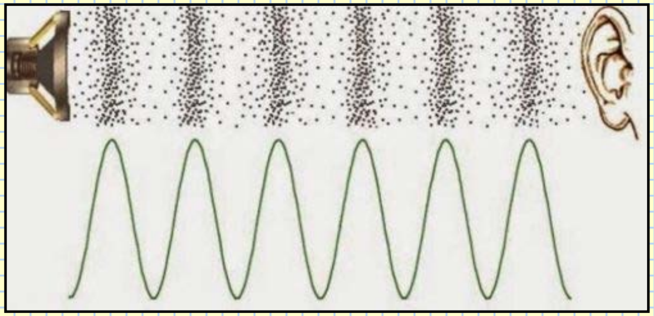
- **Jean Perrin** (1870 – 1942) experimentally verifies Einstein's predictions

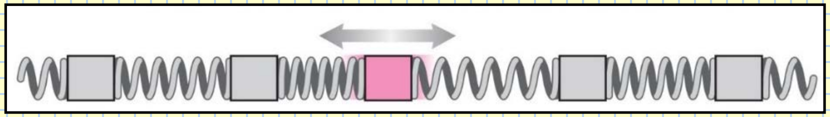
- **J.J. Thomson**

- **Ernst Rutherford**

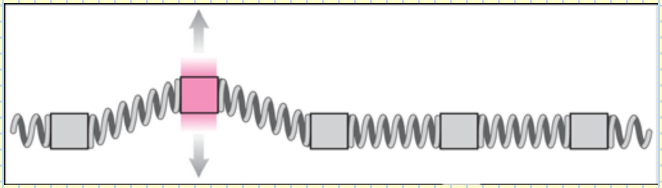


4) Mechanical Waves





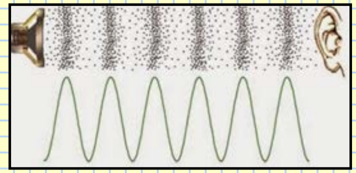
longitudinal
displacement



transverse
displacement

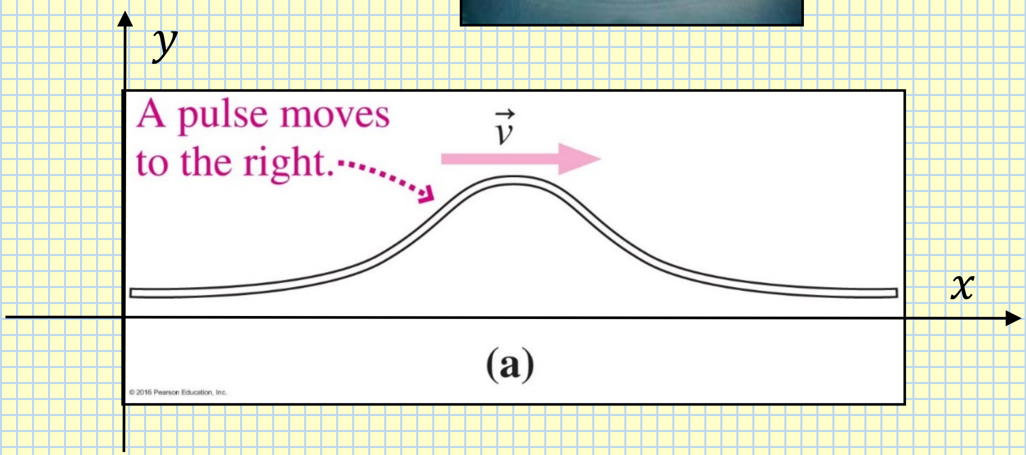
Wave Equation

$$\frac{\partial^2 \psi}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 \psi}{\partial t^2}$$



$\psi = pressure$

$\psi = height$



$$\frac{\partial^2 y(x,t)}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y(x,t)}{\partial t^2}$$

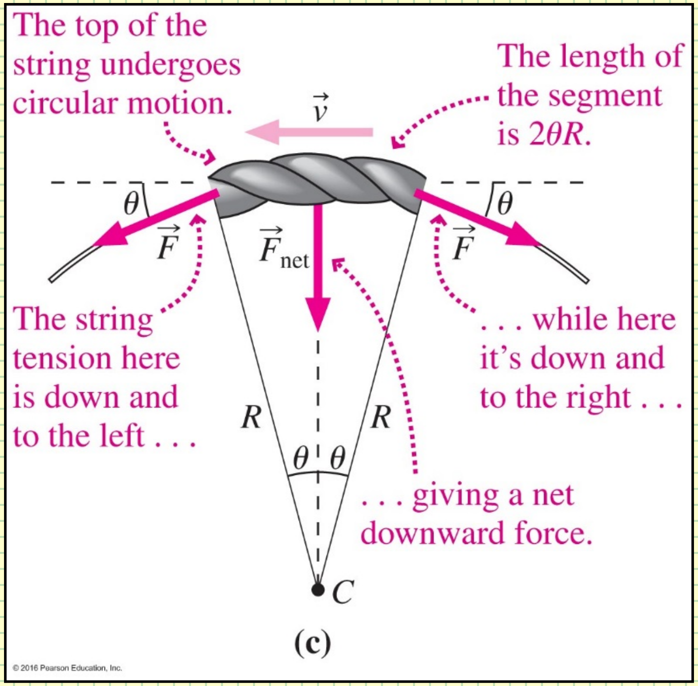
$y(x,t) = f(x - v\,t)$

Wave Speed

$$F_{net} \cong 2\, F\, \theta$$

$$m \cong 2\, \theta\, R\, \mu$$

$$a = \frac{v^2}{R}$$



$$F = m\, a$$

$$2\, F\, \theta \cong 2\, \theta\, R\, \mu \frac{v^2}{R}$$

$$v = \sqrt{\frac{F}{\mu}}$$

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. **- Albert A. Michelson, 1894**

5) A Few Dark Clouds

"two clouds on the horizon", Lord Kelvin, 1900

From the electromagnetic theory, one can derive a wave equation for the electric and magnetic fields:

$$\frac{\partial^2 E}{\partial x^2} = \frac{1}{c^2} \frac{\partial^2 E}{\partial t^2}$$

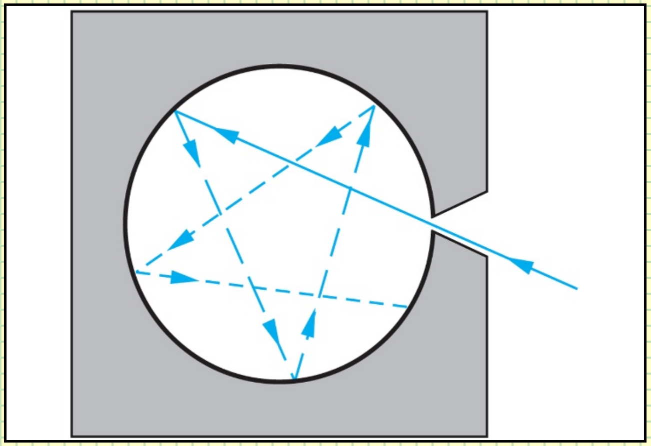
$$\frac{\partial^2 B}{\partial x^2} = \frac{1}{c^2} \frac{\partial^2 B}{\partial t^2}$$

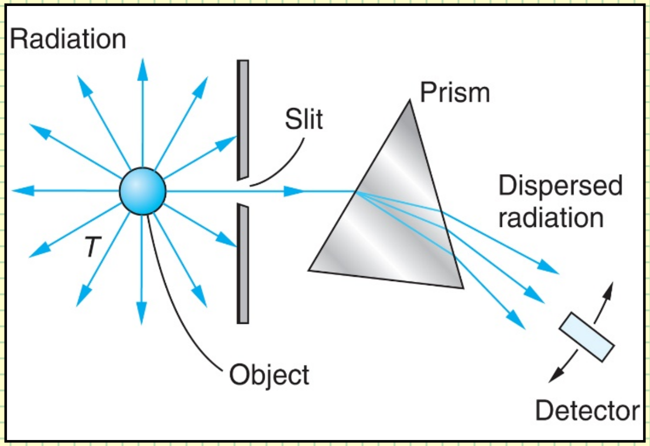
$$c = \frac{1}{\sqrt{\epsilon_o \mu_o}}$$

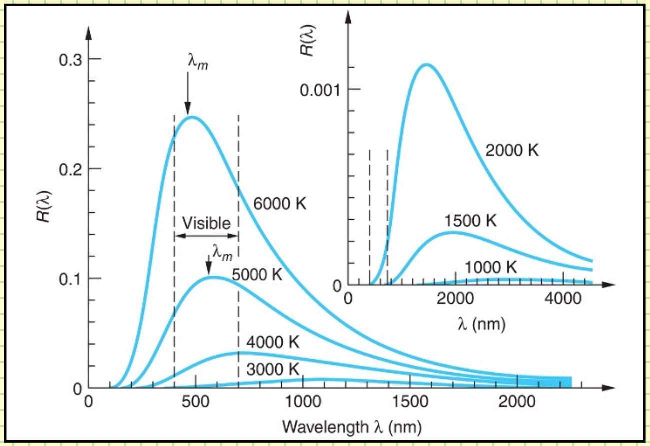
- **Where is the medium that carries the electromagnetic wave ?**
- **Are the laws of electromagnetism valid for only one particular inertial frame of reference ?**

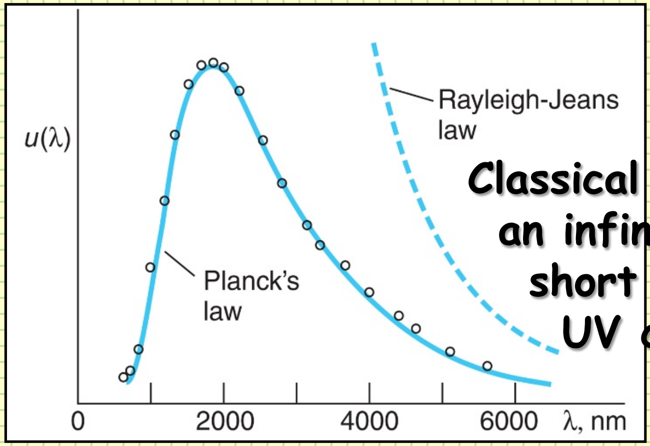
Electromagnetic Radiation in Thermal Equilibrium:

Blackbody Radiation



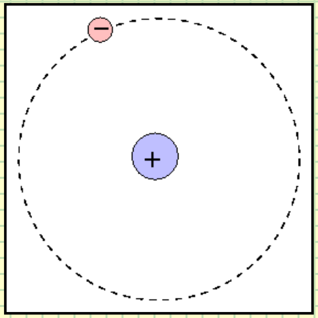






Classical theory predicts an infinite energy for short wavelengths, UV catastrophe

Consider the simplest atom (H):



- From Coulomb's law, we know that opposite charges attract each other.
- Why don't the proton and the electron collapse into each other?
- Why is the hydrogen atom (and other atoms) stable?