Thermodynamics/Optics

Survey!

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- I hate calculus!

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Overview of Last Lecture

- Foundation of physics, classical mechanics
- Copernican Revolution
- Galileo/Newton – experimentation and theory
- Social aspects – religion, economy, and intellectual society
- $\frac{dx}{dt}$
- Lagrange/Hamilton - determinism

Structure for this Lecture

- Philosophy
- Thermodynamics
  - Caloric vs. kinetic theory
  - Energy
  - Time/Entropy
- Optics
  - Fermat
  - Wave vs. Particle
- Next lecture – Electricity/Magnetism/Special Relativity

Fun and Games!

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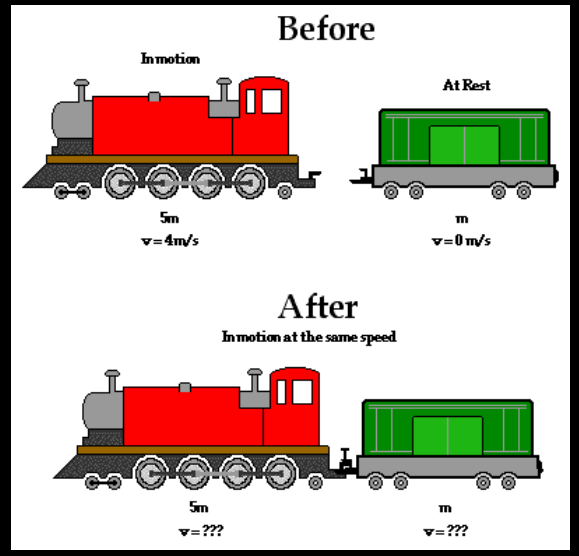
- Telephone Charades
  - Send message down the line (telephone)
  - Only acting, no talking (charades)
  - Try to be as accurate as possible
  - Find where if any problem occurs
  - Please don’t cheat

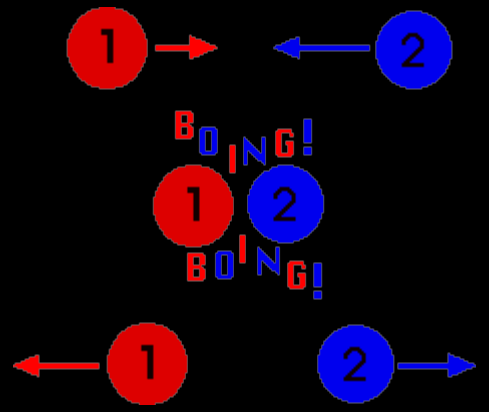
Telephone Charades

- Communication breakdown
  - Commensurability in physics (ability to understand each other)
  - Conflicting paradigms
  - Arise in explaining experimental results
- This class

What Ever Happened to $F = mv$?

- mv is the momentum of an object
- Conservation of momentum
  - Collisions preserve momentum
  - Inelastic/Elastic – sticking vs. bouncing





A Quick Test!

- Suppose I have two metal spheres which both have a mass of 10 kg. The first ball has a velocity of 10 m/s and hits the second ball which is initially at rest.
  - What happens in an inelastic collision?
  - What happens in an elastic collision?

A Quick Test!

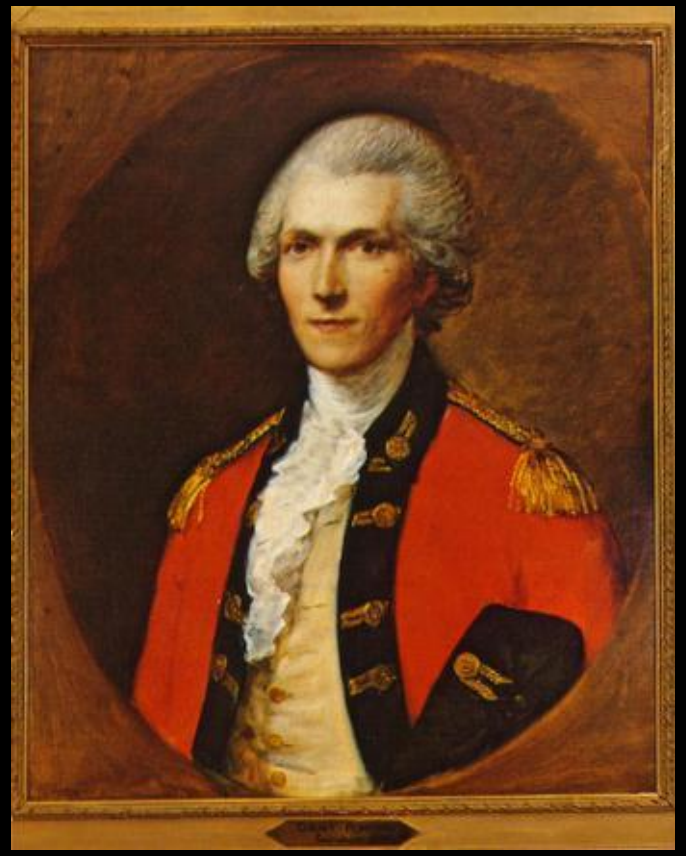
- Suppose I have two metal spheres which both have a mass of 50 kg. The first ball has a velocity of 10 m/s and hits the second ball which is initially at rest.
  - What happens in a perfectly inelastic collision?
  - What happens in a perfectly elastic collision?
- What really happens?

Thermodynamics

- Some big questions
  - What is temperature? How do we measure temperature?
  - What is heat?
  - How does heat flow?
  - What is matter made of?

Early Beginnings

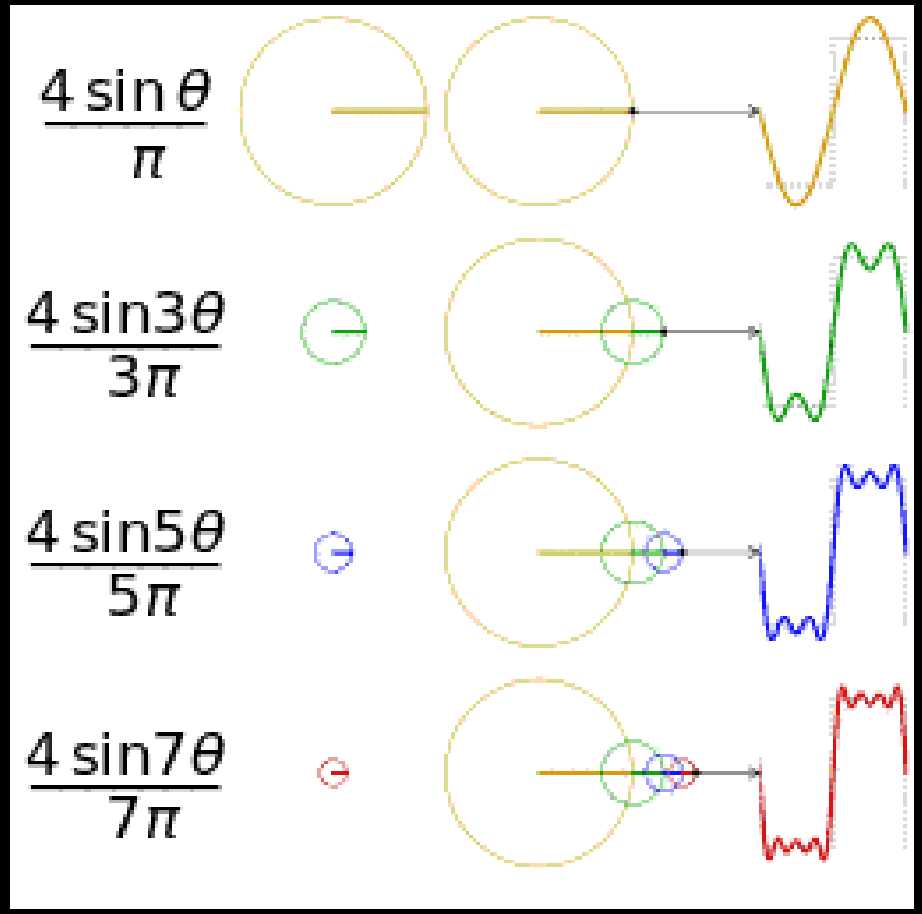
- Joseph Black (1728-1799)
  - Scottish chemist, water analogy to heat
  - Go back to Heraclitus (remember this guy?)
  - Heat is a substance, fluid
  - Caloric theory
- Count Rumford (1753-1814)
  - Loyalist soldier born in Woburn, MA
  - Royal Institution – popularize science
  - Soldier uniforms, drill cannons
  - Heat is motion
- Humphrey Davy - ice



Caloric Theory Popular

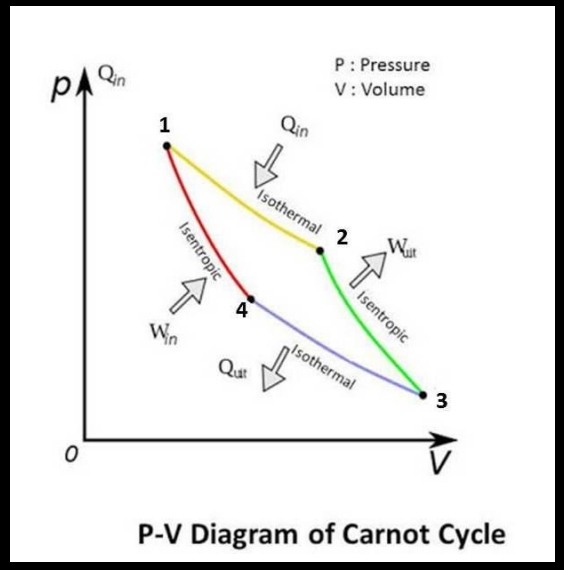
- Why?
  - Can explain thermal radiation, latent heat
    - Kinetic theory cannot yet
  - Can be quantitatively backed
- Joseph Fourier (1768-1830)
  - The heat equation
  - Series/Transform
  - Sum of sines!!!!!

$$\frac{\partial u}{\partial t} = k\frac{\partial^2 u}{\partial x^2},$$

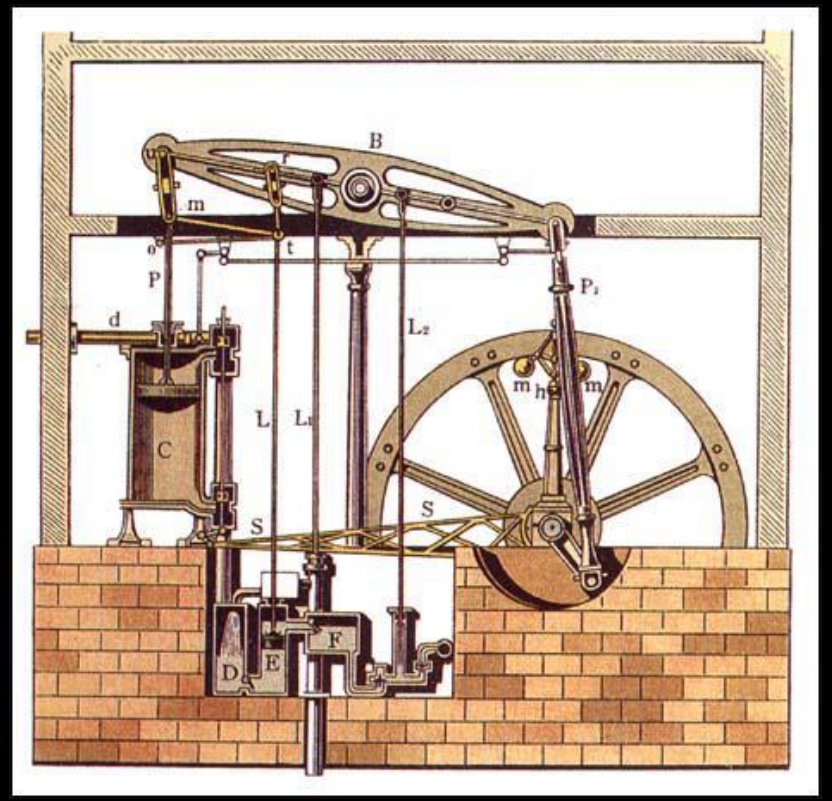

$\frac{4\sin\theta}{\pi}$
$\frac{4\sin3\theta}{3\pi}$
$\frac{4\sin5\theta}{5\pi}$
$\frac{4\sin7\theta}{7\pi}$

Technological Applications

- James Watt – steam engine
  - Industrial Revolution!!!
- Sadi Carnot – Efficiency $\eta = 1 - \frac{T_C}{T_H}$
  - Carnot cycle



P-V Diagram of Carnot Cycle



Conservation of Energy

- Three major players
- James Prescott Joule (1818-1889)
  - Brewery, very precise (1845)
  - Rotating paddles in water – electric motor
- Robert Mayer (1814-1878)
  - Rough life, purely theoretical paper (1845)
  - John Tyndall's warpath
- Hermann von Helmholtz (1821-1894)
  - First law of thermodynamics (1847)

$$\Delta U = Q - W$$

Change in internal energy

Heat added to the system

Work done by the system

A Brief Primer on Energy

- Work $W = Fd\cos\theta$
- Potential energy U, V
  - "Stored" energy
  - Chemical, electrical, gravitational
  - Defined as $-\frac{dU}{dx} = F$
- Kinetic energy K, T
  - "Living force"
  - $\frac{1}{2}mv^2$

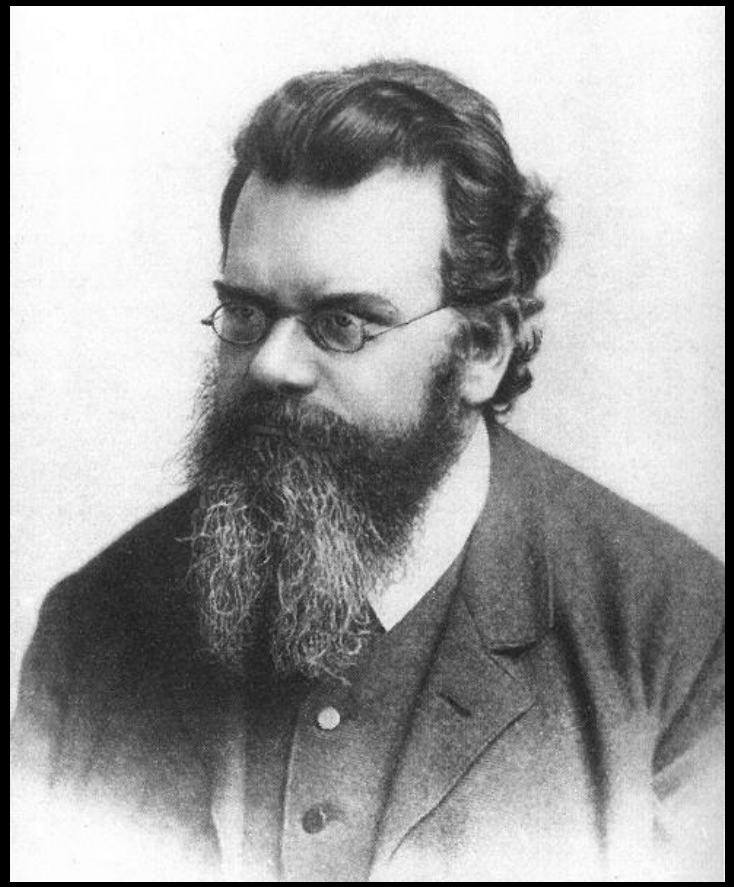
Second Law of Thermodynamics

- From Carnot's efficiency, $\eta = 1 - \frac{T_C}{T_H}$
  - Cannot use same reservoir!
  - One way to state: "Heat cannot flow from cold to hot"
  - Clausius – introduce entropy (transformation)
  - One way to state: "Entropy can only increase or stay the same"
    - Defines a change in entropy as $\mathrm{d}S = \frac{dQ}{T}$
- Arrow of time!

$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t} = -\frac{\partial \mathcal{H}}{\partial \boldsymbol{q}} \quad , \quad \frac{\mathrm{d}\boldsymbol{q}}{\mathrm{d}t} = +\frac{\partial \mathcal{H}}{\partial \boldsymbol{p}}$$

Probabilistic Revolution!

- Reviving the kinetic theory
- James Clerk Maxwell (1831-1879)
  - Introduce probability/ensembles
  - Use Hamiltonian mechanics and trace path of system
- Gibbs (1839-1903)
  - Popularize ideas of entropy/statistical mechanics
- Ludwig Boltzmann (1844-1906)
  - Rough life, Mach/Ostwald
  - $S = -k_B \sum p_i \ln p_i = k_B \log W$
- $\frac{1}{T} = \left(\frac{dS}{dU}\right)_{V,N}$

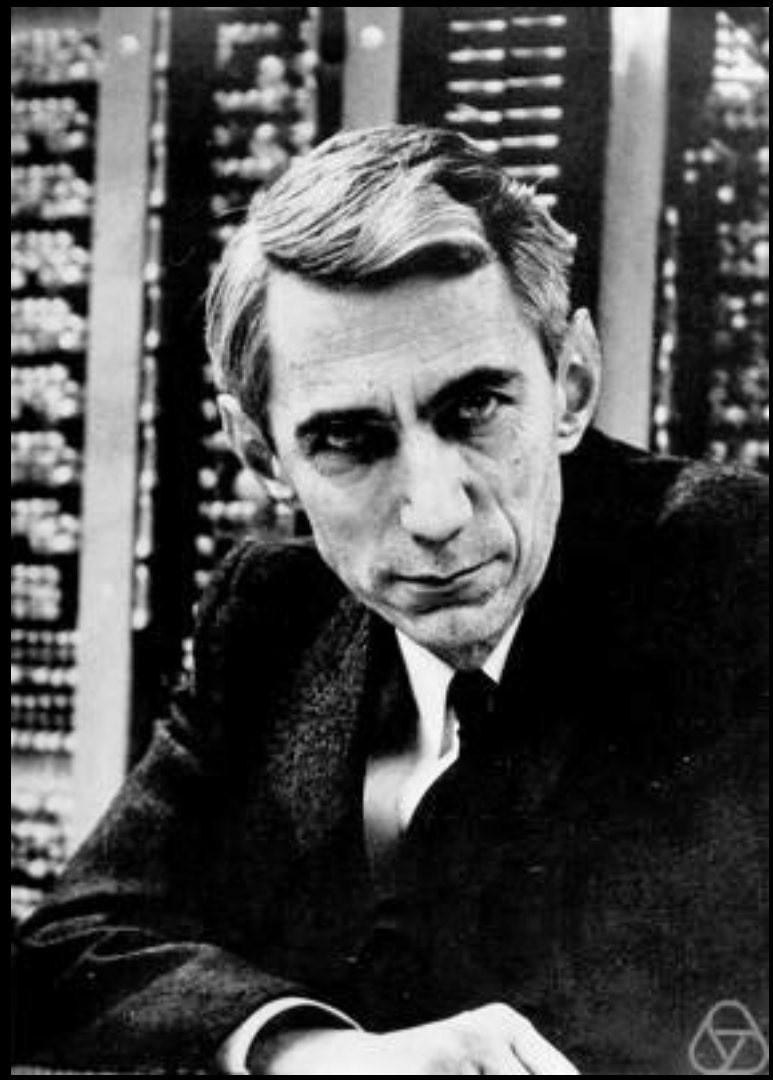


Brief Questions

- Two state system
  - Suppose you had N particles and two separate energy levels. What happens when you raise the temperature to an arbitrarily high amount and then let the system equilibrate?
- Loschmidt's paradox
  - Why can't you run it backwards?
- Zermelo's paradox
  - Eventually it will come back to the initial configuration
- Maxwell's demon
  - Hyper intelligent demon with a trap door

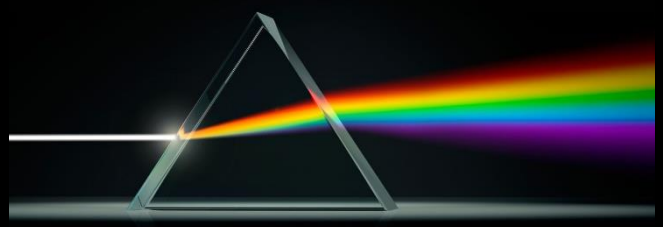
Information Theory!

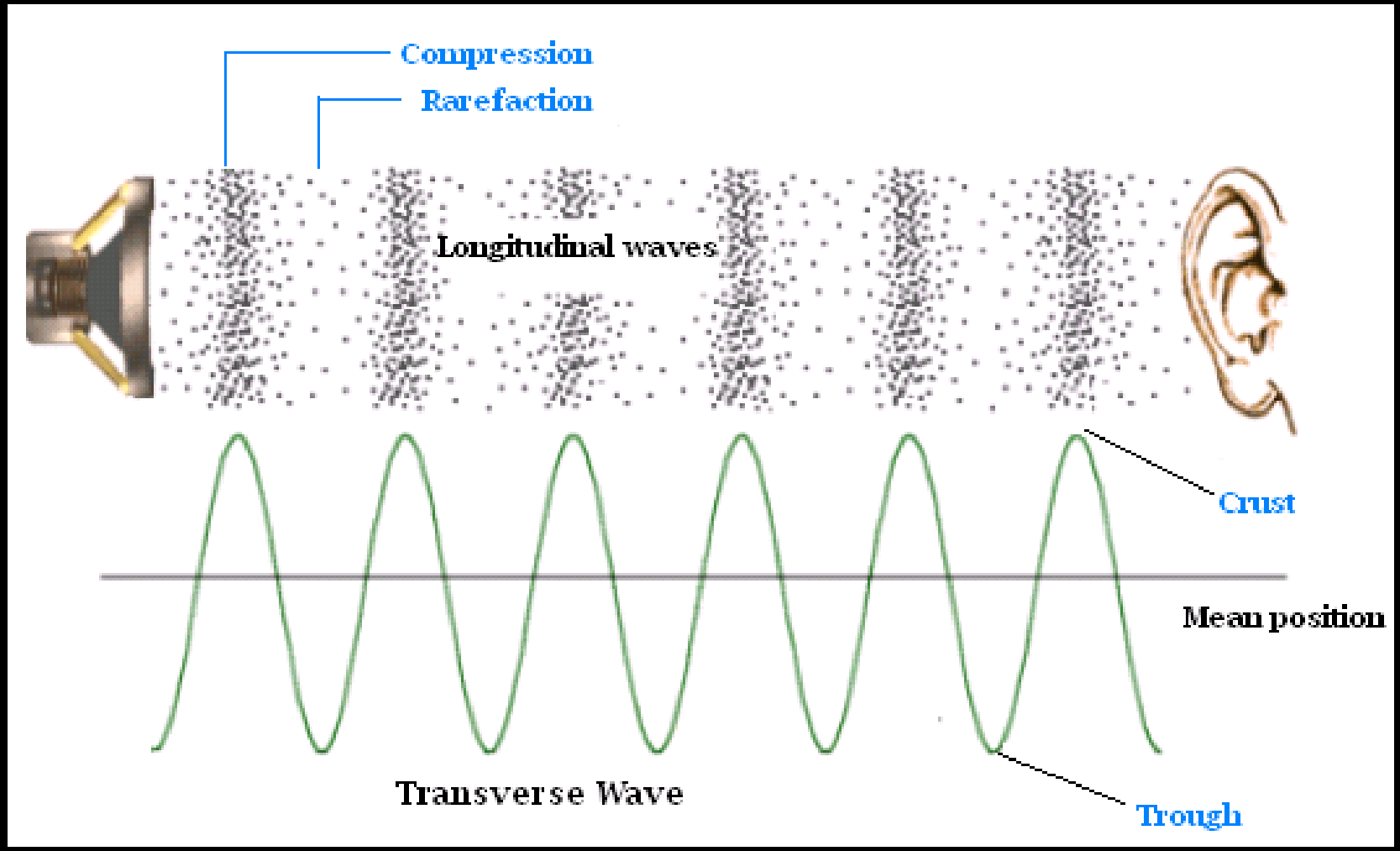
- Thermodynamic entropy
  - $S = -k_B \sum p_i \ln p_i$
- Shannon entropy (1948)
  - $S = -\sum p_i \log p_i$
- Explaining Maxwell's demon
  - Leo Szilard (1929)
- How is information physical???



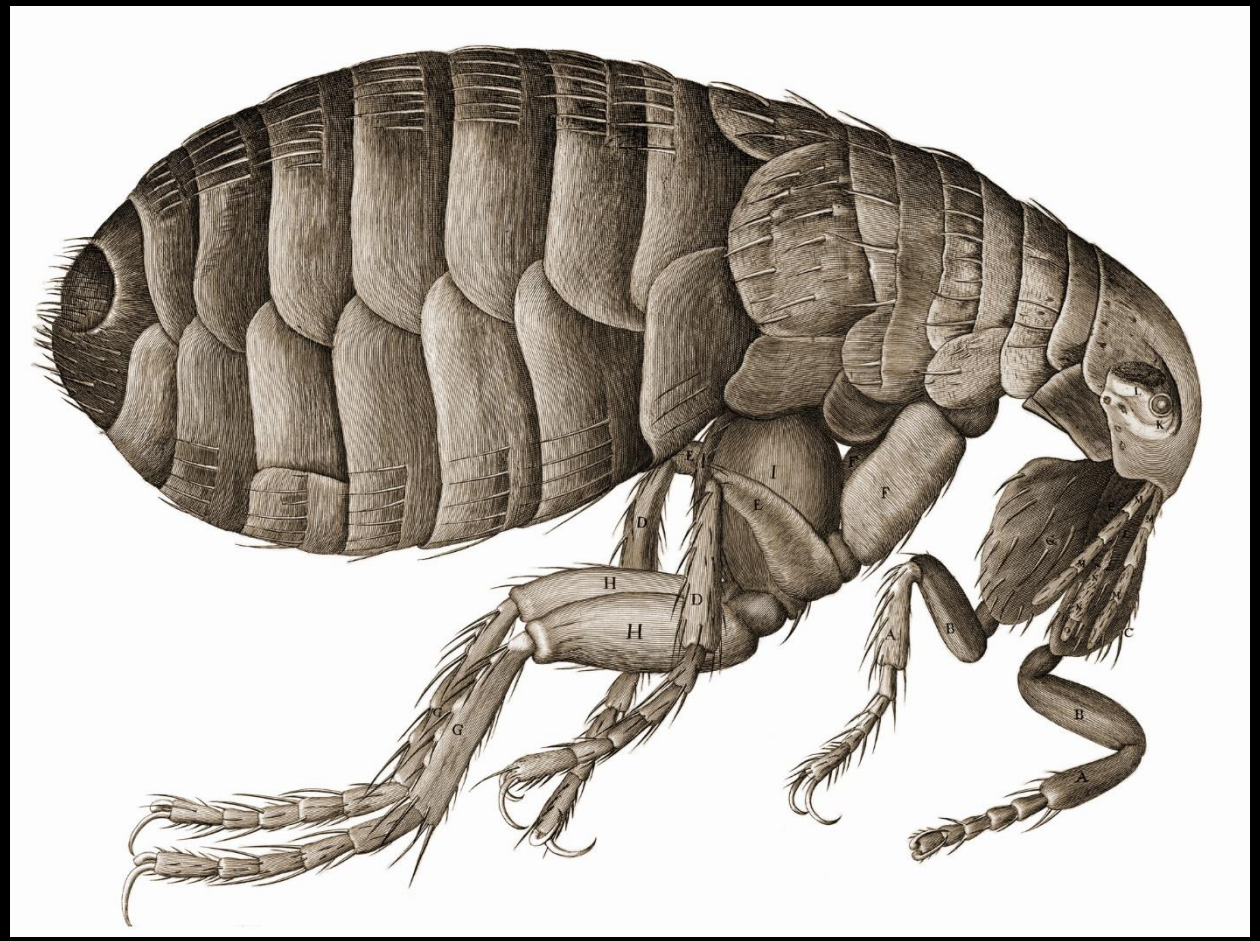
A Brief Look at Optics

- Early optics – the refinement of lens creation and telescopes plays a major role in astronomy
  - Galileo/Newton – refracting/reflecting telescope
- The main debate: particle or wave?
  - Newton – particle, also known as corpuscular theory
  - Huygens – wave (but also particles)
  - Descartes - vortices



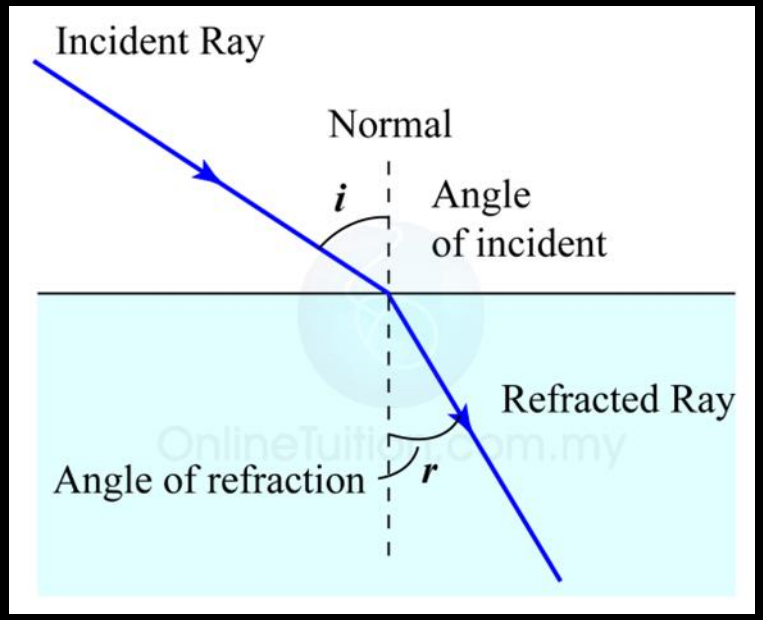

Compression
Rarefaction
Longitudinal waves
Crust
Mean position
Trough
Transverse Wave

Micrographia (1665)



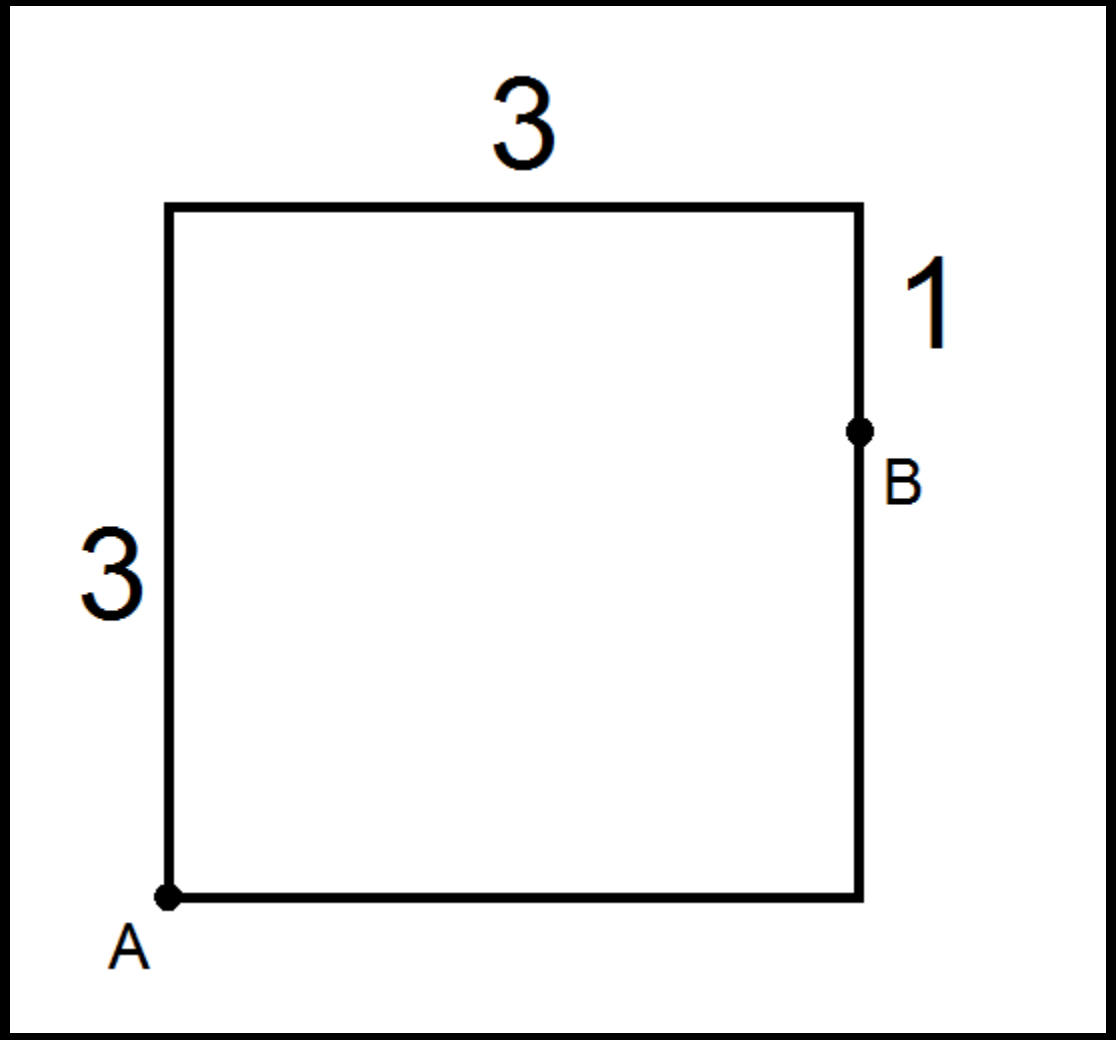
Early Discoveries

- Snell's law
  - Light refracts (bends) when entering a different medium
  - Problem: all three theories had mathematically valid explanations for phenomenon
  - Newton - light increases in velocity in media
  - Huygens - light decreases in velocity
- Fermat's principle
  - Light takes the shortest time length path
  - Optimization problem



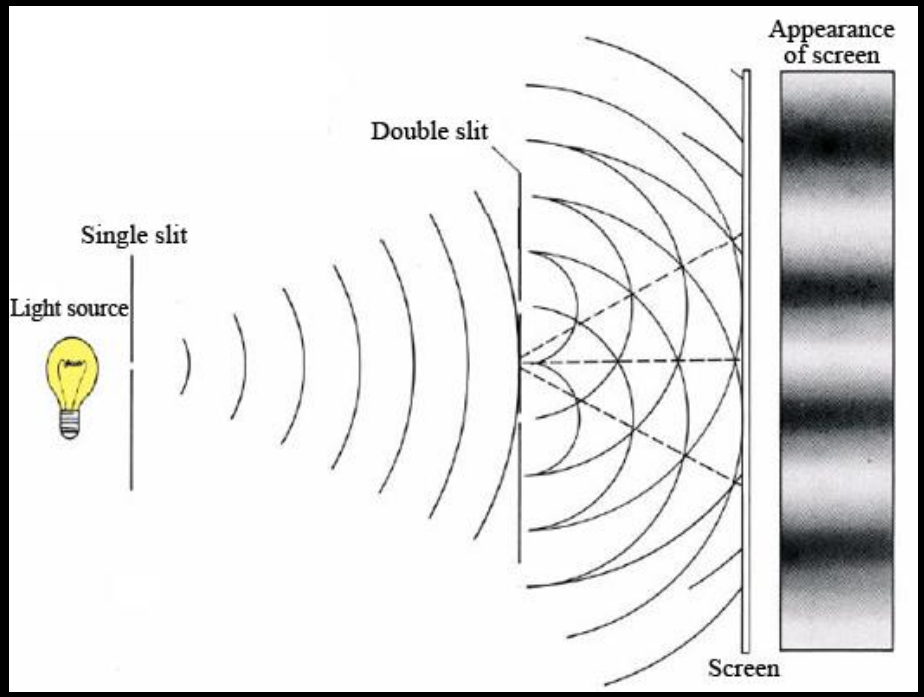

oil
Vesso
CORNING

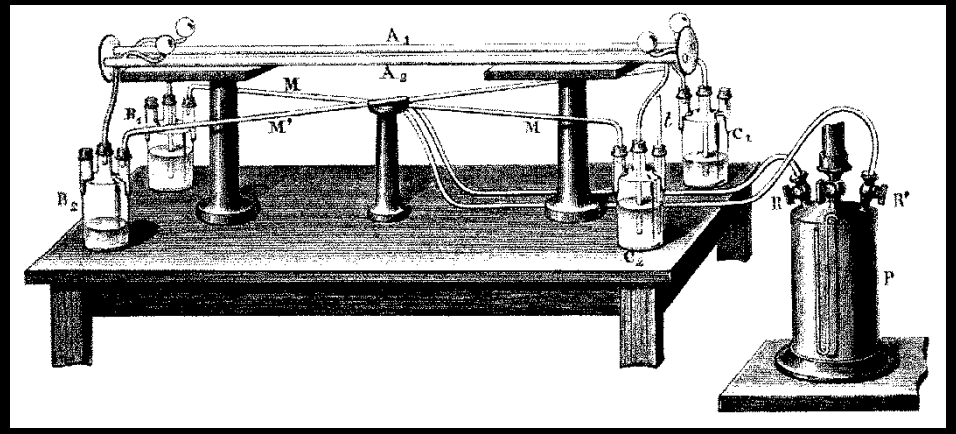
Math Question



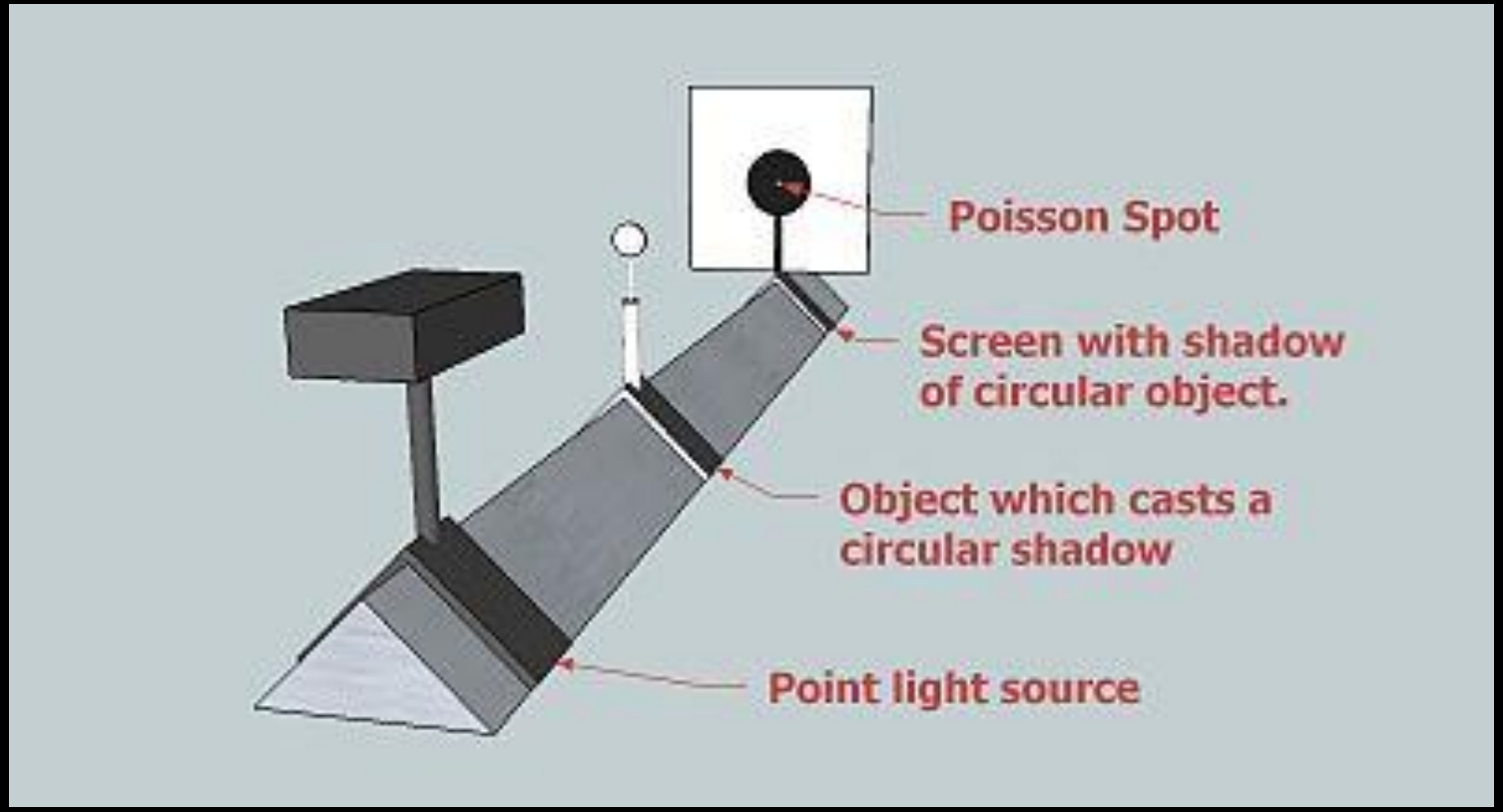
Light is a Wave!

- Thomas Young (1773-1829)
  - Double-slit experiment (1801)
  - Interference – waves collide and destroy each other
- Fizeau experiment (1851)
  - Light moves slower in water
  - Partial aether drag





Arago Spot


Poisson Spot
Screen with shadow of circular object.
Object which casts a circular shadow
Point light source