Classical Physics

- Describes objects and their interactions on a macroscopic scale
  - Mechanics
  - Electromagnetism
  - Thermodynamics
- Seemingly very successful
  - "There is nothing to be discovered in physics now. All that remains is more and more precise measurement." – Lord Kelvin (1900)

Einstein and the annus mirabilis (1905)

- “A new determination of molecular dimensions”
    - Molecular size and Avogadro's number
- “On the motion of small particles suspended in liquids at rest …”
    - Brownian motion
- “On the electrodynamics of moving bodies”
    - Special relativity
- “Does the inertia of a body depend on its energy content?”
    - $E = mc^2$
- “On a heuristic viewpoint concerning the production and transformation of light”
    - Photoelectric effect

The Birth of Quantum Mechanics

- "On the law of distribution of energy in the normal spectrum" – Planck (1901)
  - Blackbody radiation spectrum
- Quantum mechanics (QM)
  - Wave mechanics – Schrodinger (1925)
  - Matrix mechanics and the uncertainty principle – Heisenberg (1925 and 1927)
  - Dirac – Transformation theory and QM plus special relativity (1927)
  - And contributions from many others such as Bohr, Born, von Neumann, and Pauli to name a few

Newton's Laws

Three laws describing the relationship between mass and acceleration.

- **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 change in linear momentum (p):

$$\vec{F} = m\vec{a} \quad \text{or} \quad \vec{F} = \frac{d\vec{p}}{dt}$$

- **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.

$$\vec{F}_{21} = -\vec{F}_{12}$$

Maxwell's Equations

- Gauss's law (Φ_E): (electric field)

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$$

- Gauss's law (Φ_B): (magnetic field)

$$\oint \vec{B} \cdot d\vec{A} = 0$$

- Faraday's law:

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

- Ampère's law:

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 I$$

Maxwell's Equations

- In differential form

- Gauss's law (E field): $\vec{\nabla} \cdot \vec{E} = \rho / \varepsilon_0$
- Gauss's law (B field): $\vec{\nabla} \cdot \vec{B} = 0$
- Faraday's law: $\vec{\nabla} \times \vec{E} = -\dfrac{\partial \vec{B}}{\partial t}$
- Ampère's law: $\vec{\nabla} \times \vec{B} = \mu_0 \varepsilon_0 \dfrac{\partial \vec{E}}{\partial t} + \mu_0 \vec{J}$

Laws of Thermodynamics

- **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 the system plus the work W done on the system
  - $\Delta U = Q + W$
- **Second law**: It is not possible to convert heat completely into work without some other change taking place
- **Third law**: It is not possible to achieve an absolute zero temperature

Kinetic Theory of Gases

- Based on "atomic" theory of matter
- Results include
  - Speed of a molecule in a gas
    - $v_{rms} = (<v^2>)^{1/2} = (3kT/m)^{1/2}$
  - Equipartion theorem
    - Internal energy $U = f/2\ NkT = f/2\ nRT$
  - Heat capacity
    - $C_V = (dU/dT)_V = f/2\ R$
  - Maxwell speed distribution

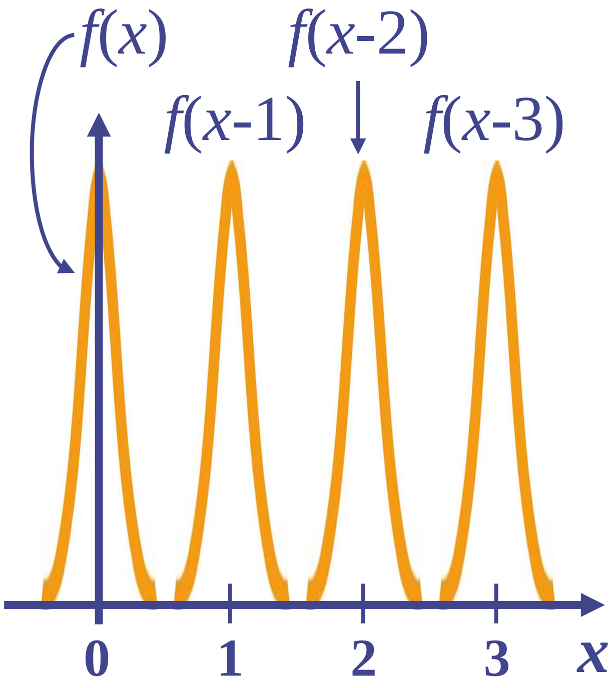
$$f(v) = 4\pi N \left(\frac{m}{2\pi kT} \right)^{3/2} v^2 e^{-mv^2/2kT}$$

Conservation Laws

- Conservation of energy
- Conservation of momentum
- Conservation of angular momentum
- Conservation of charge

Waves

- A disturbance of a continuous medium
  - Often we adopt the case of a disturbance of a continuous medium that propagates with a fixed shape at constant velocity
- For function *f(x)*, *f(x-a)* is a displacement to the right
  - Let *a=vt*, then *f(x-vt)* is a forward propagating wave
  - *v* is the wave velocity



Waves

- The disturbance *f(z,t)* satisfies the wave equation (1d case)

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

  - where *v* is the velocity of propagation
  - Energy not mass transported

- Solutions to the wave equation are

$$f(x,t) = f(x \pm \mathrm{v}t)$$

Waves

Examples

- Waves on a string
  - Transverse wave and $v = \sqrt{\frac{T}{\mu}}$
- Sound waves
  - Longitudinal wave and $v = \sqrt{\frac{B(or Y)}{\rho}}$
- In general
  - *v = √elastic property/inertial property*

Waves

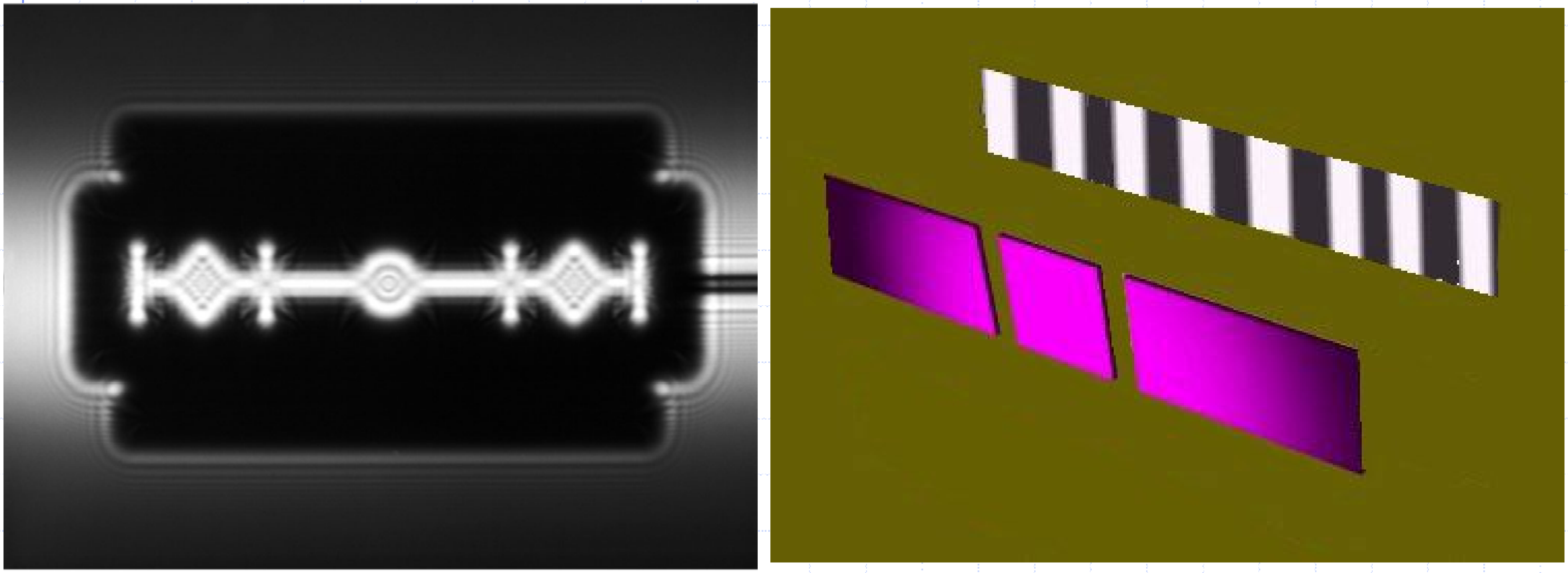
- Starting with Maxwell’s equations in a vacuum we can show that each component of the *E* and *B* fields satisfies the wave equation

$$\nabla^2 \vec{E} = \mu_0 \varepsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2} \text{ and } \nabla^2 \vec{B} = \mu_0 \varepsilon_0 \frac{\partial^2 \vec{B}}{\partial t^2}$$

- Light is an electromagnetic wave
- The speed of light is $v=1/\sqrt{\varepsilon_0 \mu_0} = 3\text{x}10^8\text{m/s}$
- But what is the medium?

Light Waves

- Experimental evidence that light is a wave comes from interference and diffraction



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