1. "Pre-Modern Physics"
   - Newton's Laws (1687) - Kinematics + Dynamics
   - Maxwell's Equations (1861) - Electromagnetism + Light

2. "Modern Physics"
   - Einstein's Relativity
     * Special Relativity (1905) → Fix Newton's equations for \( V \geq c \). Define space-time
     * General Relativity (1915) → Gravity = curvature of space-time
   - Quantum Mechanics (1900-1930s) → Description of the very small

3. "Contemporary Physics"

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**Review #1: Waves in Mechanical Systems**

From Newtonian Physics (\( F = ma \))

**Example:** Compressive Waves in a Mass/Spring System

\[ ma = F \]
\[ m \ddot{x}_n = k(x_{n+1} - x_n) - k(x_n - x_{n-1}) \]

Continuum Limit \( (\Delta x \to 0 \) while \( m \to 0 \) while \( k \to \infty \)

\[ M = \frac{m}{\Delta x} \Rightarrow \text{"density"} \]
\[ k = k_0 \Delta x \Rightarrow \text{"Young's Modulus"} \]
\( x_n(t) \rightarrow f(x, t) \equiv \text{displacement of mass at } x \text{ at time } t \)

\[
\begin{align*}
  m \frac{\partial^2 f(x,t)}{\partial t^2} &= K \left[ \frac{df(x,t)}{dx} \right]_{+} \Delta x - K \left[ \frac{df(x,t)}{dx} \right]_{-} \Delta x \\
  &= K \Delta x^2 \frac{\partial^2 f(x,t)}{\partial x^2}
\end{align*}
\]

For above, we used: \( \frac{df}{dx} = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \)

\[
\begin{align*}
  \frac{\partial^2 f}{\partial t^2} &= K \frac{\partial^2 f}{\partial x^2} \\
  \Rightarrow \text{The wave Equation!}
\end{align*}
\]

Recall Soln is \( f(x,t) = f(x \pm cw t) \quad \text{eg} \Rightarrow \sin(x - cw t) \)

(Exercise ?)

\( C_w = \sqrt{\frac{K}{\mu}} \Rightarrow \text{Speed} \)

Wave speed a property of the medium!

In general:

\( C_w = \sqrt{\frac{\text{Stiffness}}{\text{Inertia}}} \)

Solids: \( \text{eg: Steel } K = 160 \text{ GPa, } \mu = 7,700 \text{ kg/m}^3 \Rightarrow C_w = 6,000 \text{ m/s} \approx 13,000 \text{ mph} \)

\( \text{Gas: } C_w = \sqrt{\frac{8P}{\mu}} = \sqrt{\frac{\delta (nRT/V)}{\mu M/V}} = \sqrt{\frac{\delta RT}{\mu M}} \)

\( C_w \approx 340 \text{ m/s} \)
Maxwell's Eqns
\[ \nabla \cdot \mathbf{E} = 0 \]
\[ \nabla \cdot \mathbf{B} = 0 \]
\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]
\[ \nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \]

Recall "Curl of Curl" \[ \nabla \times (\nabla \times \mathbf{E}) = \nabla (\nabla \cdot \mathbf{E}) - \nabla^2 \mathbf{E} \]
\[ -\nabla^2 \mathbf{E} = -\frac{1}{2} \frac{\partial^2 \mathbf{E}}{\partial t^2} = -\frac{1}{2} \left( \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right) \]

\[ \frac{\partial^2 \mathbf{E}}{\partial t^2} = \frac{1}{\mu_0 \varepsilon_0} \frac{\partial^2 \mathbf{E}}{\partial x^2} \]

The Wave Equation!

\[ C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s} \]

If there is a medium, must be very stiff + very light.

The Problem: Newton's Laws + EM waves are inconsistent

Def: Inertial Frame = A system of coordinates in which all laws of physics take usual form.

Ex: In Newtonian mechanics, Frames traveling w/ constant relative velocity are inertial.
EM waves contradict this:
\[ \sqrt{\frac{\mu}{\varepsilon}} \]
\[ V_L = C - V \]
\[ V_R = C + V \]
Rupert

VS.

Mary

Sees light with two different velocities. Contradicts
\[ C = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \] in vacuum

The Fix:

1. Maxwell's equations only true in a preferred frame, the ether. Medium for EM wave propagation.
   - Rupert at rest in ether: \( V = C \) always
   - Mary is moving through ether: Light velocity depends on her motion relative to ether.

2. Velocity addition in Newtonian mechanics must be wrong.
   - Disproved by experiment (next week)
   - Einstein's special relativity