22. Relativity

Gerhard Müller
University of Rhode Island, gmuller@uri.edu

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Abstract
Lecture slides 22 for Elementary Physics II (PHY 204), taught by Gerhard Müller at the University of Rhode Island.
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Is There Absolute Motion?

Forces between two long, parallel, charged rods

\[ \lambda_1 > 0 \quad \lambda_2 > 0 \]

at rest

\[ \lambda_1^* > 0 \quad \lambda_2^* > 0 \]

in uniform motion

\[ \lambda_1^* = \lambda_1 \frac{1}{\sqrt{1 - v^2/c^2}} \quad \lambda_2^* = \lambda_2 \frac{1}{\sqrt{1 - v^2/c^2}} \]

(due to length contraction)

\[ \frac{F_E}{L} = \frac{1}{2\pi \epsilon_0} \frac{\lambda_1 \lambda_2}{d} \quad \text{(left)}, \quad \frac{F_{E}^*}{L} = \frac{1}{2\pi \epsilon_0} \frac{\lambda_1^* \lambda_2^*}{d}, \quad \frac{F_B}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}, \quad \text{(right)} \]

\[ \frac{F_{E}^* - F_B}{L} = \frac{1}{2\pi \epsilon_0} \frac{\lambda_1^* \lambda_2^*}{d} \left(1 - \frac{v^2}{c^2}\right) = \frac{1}{2\pi \epsilon_0} \frac{\lambda_1 \lambda_2}{d} \]

\[ c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 2.998 \times 10^8 \text{ms}^{-1} \quad \text{(speed of light)} \]
Catching Up with a Photon? (1)

Forces between two long, parallel, charged rods in relative motion.

Galilean kinematics predicts $u = v_1 + v_2$.

Relativistic kinematics requires $v_1 < c$, $v_2 < c$, $u < c$.

Relativistic dynamics requires $F_E^* - F_B = F_E$.

Length-contracted charge densities: $\lambda(v) = \frac{\lambda(0)}{\sqrt{1 - v^2/c^2}}$.

Electric currents: $I(v) = \lambda(v)v$. 
Catching Up with a Photon? (2)

\[ \frac{F_E}{L} = \frac{1}{2\pi \epsilon_0} \frac{\lambda(0) \lambda(v_1)}{d}, \quad \frac{F^*_E}{L} = \frac{1}{2\pi \epsilon_0} \frac{\lambda(v_2) \lambda(u)}{d}. \]

\[ \frac{F_B}{L} = \frac{\mu_0}{2\pi} \frac{[\lambda(v_2)v_2][\lambda(u)u]}{d} = \frac{1}{2\pi \epsilon_0} \frac{\lambda(v_2) \lambda(u) v_2 u}{d}. \]

\[ \frac{F^*_E - F_B}{L} = \frac{F_E}{L} \Rightarrow \frac{1}{2\pi \epsilon_0} \frac{\lambda(v_2) \lambda(u)}{d} \left( 1 - \frac{v_2 u}{c^2} \right) = \frac{1}{2\pi \epsilon_0} \frac{\lambda(0) \lambda(v_1)}{d} \]

\[ \Rightarrow \frac{1}{\sqrt{1 - v_2^2 c^2}} \frac{1}{\sqrt{1 - u^2 / c^2}} \left( 1 - \frac{v_2 u}{c^2} \right) = \frac{1}{\sqrt{1 - v_1^2 / c^2}} \]

\[ \text{to be solved for } u. \]

\[ \text{Relativistic kinematic predicts } u = \frac{v_1 + v_2}{1 + v_1 v_2 / c^2} < c. \]