

Justify all your answers to all problems. Write clearly.

Formulas:

Time dilation; Length contraction: $\Delta t = \gamma \Delta t_0$; $L = L_0 / \gamma$; $c = 3 \times 10^8 \text{ m/s}$

Lorentz transformation: $x' = \gamma(x - ut)$; $y' = y$; $t' = \gamma(t - ux / c^2)$

Velocity: $v'_x = \frac{v_x - u}{1 - uv_x / c^2}$; $v'_y = \frac{v_y}{\gamma(1 - uv_x / c^2)}$; $\gamma = \frac{1}{\sqrt{1 - u^2 / c^2}}$

Inverse transformations: $u \rightarrow -u$, *primed* \leftrightarrow *unprimed*; Doppler: $f' = f \sqrt{\frac{1 \pm u/c}{1 \mp u/c}}$

Momentum: $\vec{p} = \gamma m \vec{v}$; Energy: $E = \gamma mc^2$; Kinetic energy: $K = (\gamma - 1)mc^2$
 $E = \sqrt{p^2 c^2 + m^2 c^4}$; rest energy: $E_0 = mc^2$

Electron: $m_e = 0.511 \text{ MeV} / c^2$; Proton: $m_p = 938.26 \text{ MeV} / c^2$; Neutron: $m_n = 939.55 \text{ MeV} / c^2$

Atomic unit: $1u = 931.5 \text{ MeV} / c^2$; electron volt: $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$