32. Velocity addition
\[ u' = \frac{u_x - v}{1 - \frac{vu_x}{c^2}} \]
with \( v = -0.8c \) and \( u_x = 0.8c \).
\[ u'_x = \frac{0.8c - (-0.8c)(0.8c)/c^2}{1 - (0.8c)(0.8c)/c^2} = \frac{1.6c}{1.64} = 0.976c \]

* 37. Classical:
\[ t = \frac{4205 \text{ m}}{0.98c} = 1.43 \times 10^{-5} \text{ s} \]
Then
\[ N = N_0 \exp \left[ -\frac{(\ln 2) t}{t_{1/2}} \right] = 14.6 \text{ or about 15 muons} \]
Relativistic:
\[ t' = t/\gamma = \frac{1.43 \times 10^{-5} \text{ s}}{5} = 2.86 \times 10^{-6} \text{ s} \]
\[ N = N_0 \exp \left[ -\frac{(\ln 2) t}{t_{1/2}} \right] = 2710 \text{ muons} \]
Because of the exponential nature of the decay curve, a factor of five (shorter) in time results in many more muons surviving.

40. \( T = t_1 + t_2 = \frac{L}{v} + \frac{L}{c} + \frac{L}{v} - \frac{L}{c} = \frac{2L}{v} \)
Frank sends signals at rate \( f \), so Mary receives \( fT = 2fL/v \) signals.
\[ T' = t'_1 + t'_2 = \frac{2L}{\gamma v} \]
Mary sends signals at rate \( f \), so Frank receives \( fT' = 2fL/\gamma v \) signals.

* 51.
\[ f = f_0 \sqrt{\frac{1 - \beta}{1 + \beta}} = (400 \text{ Hz}) \sqrt{\frac{1 - 0.92}{1 + 0.92}} = 82 \text{ Hz} \]

* 54. The Doppler shift to higher wavelengths is (with \( \lambda_0 = 589 \text{ nm} \))
\[ \lambda = 700 \text{ nm} = \lambda_0 \sqrt{\frac{1 + \beta}{1 - \beta}} \]
Solving for \( \beta \) we find \( \beta = 0.171 \). Then
\[ t = \frac{v}{a} = \frac{(0.171) (3.00 \times 10^8 \text{ m/s})}{25 \text{ m/s}^2} = 2.052 \times 10^6 \text{ s} \]
which is 23.75 days. One problem with this analysis is that we have only computed the time as measured by earth. We are not prepared to handle the non-inertial frame of the spaceship.

* 55. Let the instantaneous momentum be in the \( x \)-direction and the force be in the \( y \)-direction. Then \( d\vec{p} = \vec{F} \, dt = \gamma m \, d\vec{v} \) and \( d\vec{v} \) is also in the \( y \)-direction. So we have
\[ \vec{F} = \gamma m \frac{d\vec{v}}{dt} = \gamma m \vec{a} \]
\[ \vec{p} = \gamma m \vec{v} = \frac{m \vec{v}}{\sqrt{1 - \frac{v^2}{c^2}}} \]

\[ \vec{F} = \frac{d \vec{p}}{dt} \]

The momentum is the product of two factors that contain the velocity, so we apply the product rule for derivatives:

\[
\vec{F} = m \frac{d}{dt} \left[ \frac{m \vec{v}}{\sqrt{1 - \frac{v^2}{c^2}}} \right] \\
= m \left[ \frac{d\vec{v}}{dt} \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} + \vec{v} \frac{d}{dt} \left( \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \right) \right] \\
= \gamma m \ddot{a} + m \vec{v} \left( \frac{1}{2} \right) \left( -\frac{2v}{c^2} \right) \gamma^3 \frac{dv}{dt} \\
= \gamma m \ddot{a} + \gamma^3 m \ddot{a} \left( \frac{v^2}{c^2} \right) \\
= \gamma^3 m \ddot{a} \left[ 1 - \frac{v^2}{c^2} + \frac{v^2}{c^2} \right] = \gamma^3 m \ddot{a}
\]

* 68. \( E = 2E_0 = \gamma E_0 \) so \( \gamma = 2 \). Then

\[ \beta = \sqrt{1 - \frac{1}{\gamma^2}} = \frac{\sqrt{3}}{2} \]

and \( v = \frac{\sqrt{3}c}{2} \).

76. The energy needed equals the kinetic energy of the spaceship.

\[ K = (\gamma - 1) mc^2 = \left( \frac{1}{\sqrt{1 - \beta^2}} - 1 \right) mc^2 \]

\[ = \left( \frac{1}{\sqrt{1 - 0.3^2}} - 1 \right) (10^4 \text{ kg}) (3.00 \times 10^8 \text{ m/s})^2 = 4.35 \times 10^{19} \text{ J} \]

or 4.35% of \( 10^{21} \text{ J} \).

80.

\[ \Delta E = [m_n - m_p - m_e] c^2 \]

\[ = [1.008665 \text{ u} - 1.007276 \text{ u} - 0.000549 \text{ u}] c^2 \left( \frac{931.494 \text{ MeV}}{c^2 \cdot \text{u}} \right) = 0.782 \text{ MeV} \]

82. a) \( E = \sqrt{p^2 c^2 + E_0^2} = \sqrt{(30 \text{ GeV})^2 + (511 \text{ keV})^2} \approx 30.0 \text{ GeV} \)

\[ K = E - E_0 = 30.0 \text{ GeV} \]

b) \( E = \sqrt{p^2 c^2 + E_0^2} = \sqrt{(30 \text{ GeV})^2 + (0.938 \text{ GeV})^2} = 30.015 \text{ GeV} \)

\[ K = E - E_0 = 30.015 \text{ GeV} - 0.938 \text{ GeV} = 29.08 \text{ GeV} \]
86. a) In the inertial frame moving with the negative charges in wire 1, the negative charges in wire 2 are stationary, but the positive charges are moving. The density of the positive charges in wire 2 is thus greater than the density of negative charges, and there is a net attraction between the wires.

b) By the same reasoning as in (a), note that the positive charges in wire 2 will be stationary and have a normal density, but the negative charges are moving and have an increased density, causing a net attraction between the wires.

c) There are two facts to be considered. First, (a) and (b) are consistent with the physical result being independent of inertial frame. Second, we know from classical physics that two parallel wires carrying current in the same direction attract each other. That is, the same result is achieved in the "lab" frame.

92. a) \( K = E + E_0 = 200E_0 \) so \( K = 199E_0 = 199 \times (511 \text{ keV}) = 102 \text{ MeV} \)

b) \( \gamma = 200 \)

\[
\beta = \sqrt{1 - \frac{1}{\gamma^2}} = 0.9999875 \\
v = 0.9999875c \\

\]

c) 
\[
p = \frac{\sqrt{E^2 - E_0^2}}{c} = \frac{\sqrt{(200 \times 511 \text{ keV})^2 - (511 \text{ keV})^2}}{c} = 102 \text{ MeV/c}
\]

CHAPTER 12

26. 
\[ R = R_0 e^{-\lambda t} = \frac{R_0}{5} \text{ at } t = T = 3600 \text{ s} \]

\[ \lambda = \frac{\ln 5}{T} \]

\[ t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{\ln 5} T = \frac{\ln 2}{\ln 5} (3600 \text{ s}) = 1550 \text{ s} \approx 26 \text{ minutes} \]