

## PHYS-3301 Winter Homework 5 Due 14 Feb 2018

This homework is due in the dropbox outside 2L26 by 10:59PM on the due date. You may alternately email a PDF (typed or black-and-white scanned) or give a hardcopy to Dr. Frey.

### 1. Invariance of Light Speed

In this question, we'll show that the speed of light is invariant, no matter the direction of the velocity. (Of course, our derivation of the Lorentz transformations showed this for light moving along the relative motion of two frames.) Start in the  $S$  frame, where a light beam leaves the origin at time  $t = 0$  and reaches point  $\vec{x} = (x_0, y_0, 0)$  at time  $t = \sqrt{x_0^2 + y_0^2}/c$ , hitting a detector there. Now consider a frame  $S'$  moving at speed  $v$  relative to  $S$  along the  $x$  axis.

- At what coordinates  $t', x', y', z'$  does the light hit the detector? Write your answer in terms of  $c, x_0, y_0$ , and  $v$ .
- Find the components of the light's velocity in the  $S'$  frame by dividing  $x'/t'$ , etc. What is the speed of light in  $S'$ ?
- Why don't we need to think about a component of motion along the  $z$  axis to get a general proof of the invariance of the speed of light?

### 2. Relativistic Courier

A spaceship is equipped with a relativistic courier system for delivering packages throughout the ship at speed  $c/5$  relative to the ship. Assume the package moves at constant velocity.

- Suppose the spaceship flies past a space buoy at speed  $3c/5$ , and a courier package leaves the tail of the ship when the tail is at the buoy's position. If the ship has proper length  $L$ , how far does the package travel to reach the head of the ship in the rest frame of the buoy? How long does it take in the buoy's rest frame?
- Based on your answer to the previous problem, what is the speed of the courier package in the buoy's frame? (We will learn how to convert velocities directly later in the term.)

### 3. Relativistic Monorail *inspired by Resnick & Halliday and by Hartle*

A monorail stretches between two halves of a large starbase. There are lights attached to the monorail, evenly spaced with separation  $L$  in the rest frame of the base, and the lights flash simultaneously in that frame. In the frame of the train moving along the monorail, the lights are a distance  $12L/13$  apart.

- Use length contraction to find the speed of the train with respect to the monorail.
- In the train's frame, how long is it between flashes of neighboring lights? Does the light in front of the train (ie, the one the train is moving toward) flash before or after the light behind the train?
- The rear of the train passes one of the lights just as it flashes. How much time passes before the light reaches the front of the train in the train's frame? In the frame of the starbase? The proper length of the train is  $L/3$ .