# Rain and Relativity

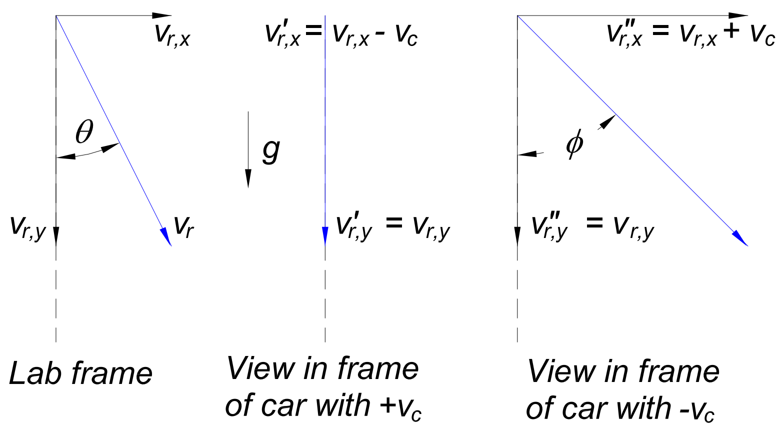
Kirk T. McDonald
*Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544*
(October 10, 2013)

# 1 Problem

Rain is falling steadily with speed $v_r$ in the lab frame, making angle $\theta$ to the vertical. When an observer drives in a car with horizontal speed $v_c$ (in the plane of vector $\mathbf{v}_r$) the rain appears to be falling vertically. When the observer drives in the opposite direction with speed $v_c$ the rain appears to make angle $\phi$ to the vertical. What are $\theta$ and $v_r$ in terms of $\phi$ and $v_c$?

# 2 Solution

We analyze this problem by consider two frames in addition to the lab frame: the $'$ frame which has horizontal speed $v_c$ with respect to the lab frame, and the $''$ frame which has horizontal speed $-v_c$ with respect to the lab frame, where the rain in the lab frame has positive horizontal ($x$) component.




The components of the rain-velocity vectors $\mathbf{v}'_r$ and $\mathbf{v}''_r$ are given by the Galilean transformations,

$$v'_{r,x} = v_{r,x} - v_c, \qquad v''_{r,x} = v_{r,x} + v_c, \tag{1}$$

$$v'_{r,y} = v_{r,y} = v''_{r,y}. \tag{2}$$

Then,

$$v'_{r,x} = 0 \qquad \Rightarrow \qquad v_{r,x} = v_r \sin\theta = v_c, \qquad v''_{r,x} = 2v_c = 2v_r \sin\theta, \tag{3}$$

and.

$$v''_{r,y} = v_{r,y} = v_r \cos\theta, \tag{4}$$

so that.

$$\tan\phi = \frac{v''_{r,x}}{v''_{r,y}} = \frac{2v_r \sin\theta}{v_r \cos\theta} = 2\tan\theta, \tag{5}$$

$$\tan\theta = \frac{\tan\phi}{2}. \tag{6}$$

Also,

$$\sin\theta = \frac{\tan\theta}{\sqrt{1+\tan^2\theta}} = \frac{\tan\phi}{\sqrt{4+\tan^2\phi}}, \tag{7}$$

so,

$$v_r = \frac{v_c}{\sin\theta} = v_c \frac{\sqrt{4+\tan^2\phi}}{\tan\phi}. \tag{8}$$