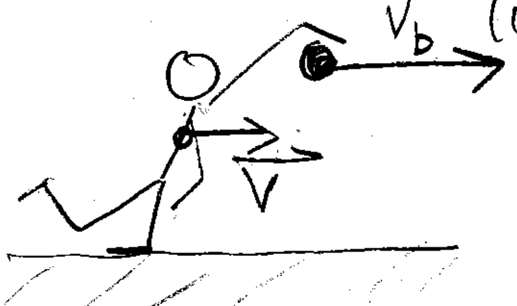
Three ideas to help understand relativity:

(1) Throw a ball at speed $|\vec{v}_b|$ relative to you while running at speed $|\vec{v}|$

$\vec{v}_b$ (w/r to person)

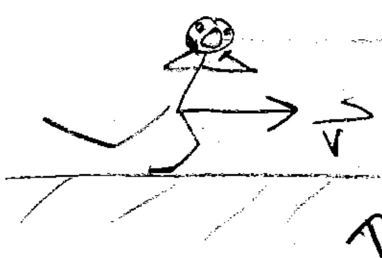


$\vec{v}_b + \vec{v}$

ball goes at $\vec{v}_b + \vec{v}$ rel to ground

jump to person's frame, subtract $\vec{v}$

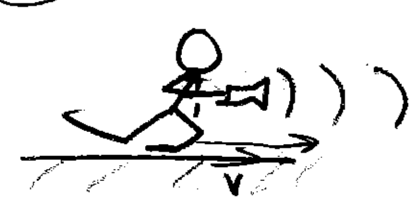
(2) Call at speed of sound while running $\vec{v}_s$ ← determined by still air relative to ground



runner perceives sound moving at $\vec{v}_s - \vec{v}$

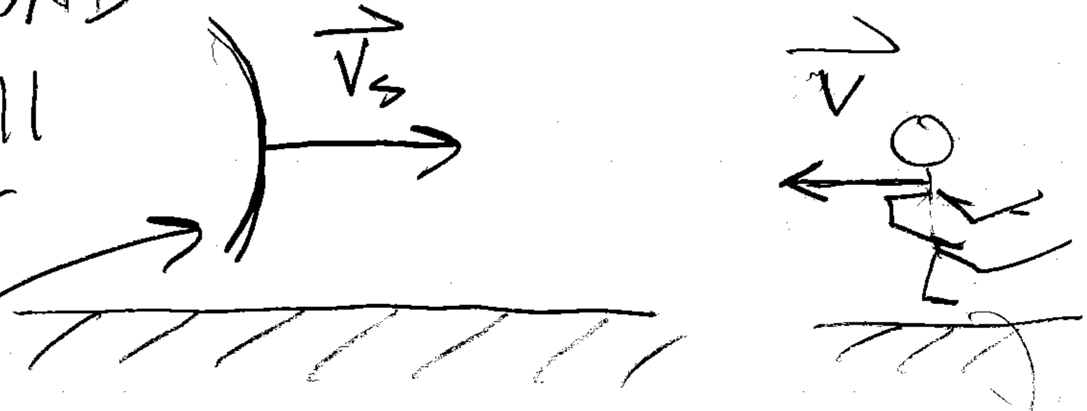
(3) Light

(a) moves at c w/r to ground



(b) moves at c w/r to person

SOUND
still
air



moves with velocity $\vec{V_s}$, horizontal $|\vec{V_s}| = V_s$

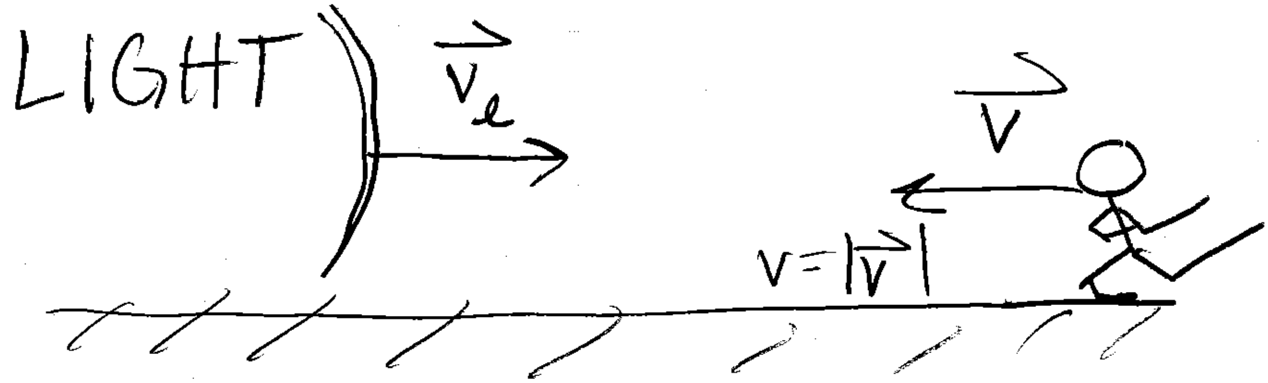
runs horizontal velocity $\vec{V}$, right to left $|\vec{V}| = V$

<u>Speed</u> of sound perceived by runner:

A $V_s + V$

B V_s

C $V_s - V$



$$|\vec{v}_e| = c = 3 \cdot 10^8 \ m/s$$

relative to ground

Speed of light perceived by runner:

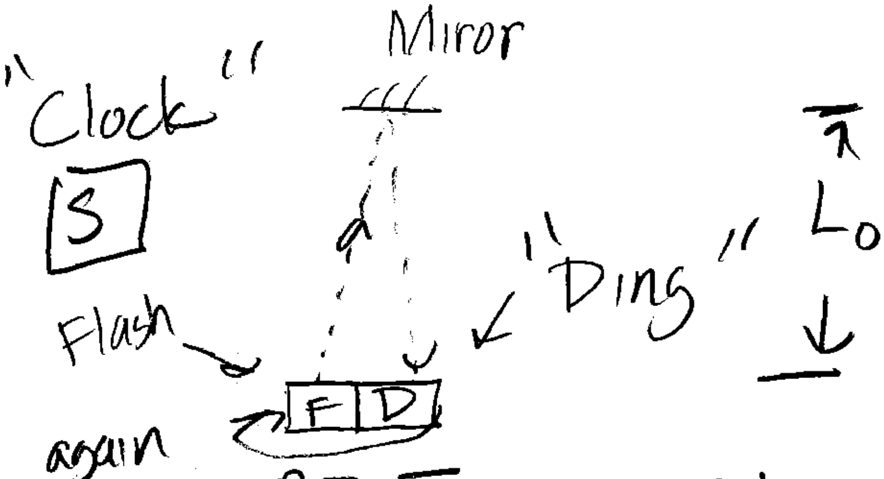
(A) $c + v$

(B) c

(C) $c - v$

How this is resolved

Time Dilitation



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AT REST, $\underbrace{c\,\Delta t_0}_{\text{time between ``Dings''}} = 2L_0$ $\qquad \Delta t_0 = \frac{2L_0}{c}$

$$u\,\underbrace{\Delta t}_{\text{hmm}}$$

$$L^2 = L_0^2 + \left(\frac{u\Delta t}{2}\right)^2 \qquad \text{Pythag}$$

$$\Delta t = \frac{2L}{c} = \frac{2}{c}\sqrt{L_0^2 + \left(\frac{u\Delta t}{2}\right)^2} \qquad \text{SOLVE!}$$

$$\left(\frac{c\Delta t}{2}\right)^2 = L_0^2 + \left(\frac{u}{2}\Delta t\right)^2$$

$$\frac{1}{\cancel{4}}\left[(c\Delta t)^2 - (u\Delta t)^2\right] = \left(\frac{c\Delta t_0}{\cancel{2}}\right)^2$$

$$(\Delta t)^2(c^2 - u^2) = c^2(\Delta t_0)^2$$

$$\Delta t = \frac{c\,\Delta t_0}{\sqrt{c^2-u^2}} = \frac{\Delta t_0}{\sqrt{1-\left(\frac{u}{c}\right)^2}}$$

$$\beta \equiv \frac{u}{c} \qquad \gamma \equiv \frac{1}{\sqrt{1-\left(\frac{u}{c}\right)^2}}$$

$$= \frac{1}{\sqrt{1-\beta^2}} > 1$$

$$\Delta t = \gamma \Delta t_0$$

Longer time interval in the rest frame

$\mu^{\pm}$ particles: $\Delta t \simeq 2.2 \cdot 10^{-6}$ s

($c\Delta t \simeq 2200$ ft)

but: they travel 30,000 ft from top of atmosphere