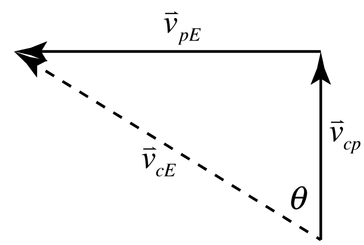
Example Problem: A toy car travels at 46 mm/s N relative to a piece of paper that is moving at 75 mm/s W relative to the Earth. (a) What is the velocity of the toy car relative to the Earth? (b) If the width of the paper necessary for the toy car to cross is 69.2 cm, how far did the toy car actually travel? (c) How long did it take the toy car to cross the paper?



Givens: $\vec{v}_{cp} = 46\frac{mm}{s}N$, $\vec{v}_{pE} = 75\frac{mm}{s}W$, $\vec{v}_{cE} = ?$

$\vec{v}_{cE} = \vec{v}_{cp} + \vec{v}_{pE}$ & $a^2 + b^2 = c^2 \Rightarrow v_{cp}^2 + v_{pE}^2 = v_{cE}^2$

(The velocity of the car with respect to the Earth is the same as the velocity of the car with respect to the paper plus the velocity of the paper with respect to the Earth; the paper drops out of the equation.)

$\Rightarrow v_{cE} = \sqrt{v_{cp}^2 + v_{pE}^2} = \sqrt{46^2 + 75^2} = 87.983\frac{mm}{s} \approx 88\frac{mm}{s}$ (magnitude only)

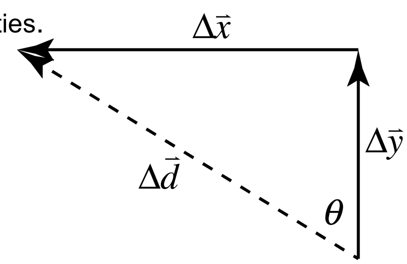
Now we need the direction of the velocity *vector*.

$$\tan\theta = \frac{O}{A} = \frac{v_{pE}}{v_{cp}} \Rightarrow \theta = \tan^{-1}\left(\frac{v_{pE}}{v_{cp}}\right) = \tan^{-1}\left(\frac{75}{46}\right) = 58.478° \approx 58°$$

$$\Rightarrow \vec{v}_{cE} \approx \boxed{88\frac{mm}{s} @ 58° W\ of\ N}$$

Part (b): Now we draw a similar triangle with displacements instead of velocities.

$\Delta d = ?$ (magnitude only, not displacement)



New given for part (b): $\Delta\vec{y} = 69.2cm\ N \times \frac{1m}{100cm} \times \frac{1000mm}{1m} = 692mm\ N$

Because they are similar triangles, cosθ will have the same value for both.

$$\cos\theta = \frac{A}{H} = \frac{v_{cp}}{v_{cE}} = \frac{\Delta y}{\Delta d} \Rightarrow \frac{v_{cp}}{v_{cE}}(\Delta d) = \frac{\Delta y}{\Delta d}(\Delta d) \Rightarrow \frac{v_{cp}}{v_{cE}}(\Delta d) = \Delta y$$

$$\Rightarrow \frac{v_{cp}}{v_{cE}}(\Delta d)\left(\frac{v_{cE}}{v_{cp}}\right) = \Delta y\left(\frac{v_{cE}}{v_{cp}}\right) \Rightarrow (\Delta d) = \frac{(\Delta y)(v_{cE})}{v_{cp}} = \frac{(692)(87.983)}{46} = 1323.57mm \approx \boxed{1300mm}$$

Part (c): The car is moving at a constant velocity. $\Delta t = ?$

$$\vec{v} = \frac{\Delta\vec{x}}{\Delta t} \Rightarrow v_{cE} = \frac{\Delta d}{\Delta t} \Rightarrow \Delta t = \frac{\Delta d}{v_{cE}} = \frac{1323.57mm}{87.983\frac{mm}{s}} = 15.043 \approx \boxed{15\sec}$$

Or we could have used the y-direction instead:

$$\vec{v} = \frac{\Delta\vec{x}}{\Delta t} \Rightarrow v_{cp} = \frac{\Delta y}{\Delta t} \Rightarrow \Delta t = \frac{\Delta 7}{v_{cp}} = \frac{692mm}{46\frac{mm}{s}} = 15.043 \approx \boxed{15\sec}$$