Lesson 16: Relative Motion

A **frame of reference** can be thought of as any spot your doing your measurement from as long as it is **not** accelerating. This is called an *inertial frame of reference*.

Relative motion is just a way of saying that sometimes different people will say different things about the motion of the same object.

- This is not because one of them is wrong, but because they are using different **frames of reference**.
- The best way to see how this is possible is to look at some examples.
- In all of the following examples, ignore air resistance.

1-D Relative Motion

Example 1: Let's say I am standing on the back of a pickup truck (that is motionless), and I am throwing apples forwards. I know that I can throw an apple at exactly 15m/s every time.

- If a person were standing on the sidewalk, how fast would she say the apples are moving?
    - Since she will see them exactly the same way as me (we're both in the same reference frame), she will say 15m/s.
- Now the truck starts to move forwards at 20m/s. I am still throwing apples forwards, exactly the same as I was throwing them before, at 15m/s.
    - If I am really not paying attention to what's going on around me (like the fact that I am standing in the back of a moving truck), how fast would I say the apples are moving?
    - Still 15m/s! Relative to me, I can only make an apple move away from me at 15m/s, so that's how fast I measure the apple moving away from me.
- How fast does my friend on the sidewalk say the apple is moving?
    - Well, even before I throw it, she'll say that the apple is moving at 20m/s (the speed of everything on the truck).
    - When I have thrown the apple forward, adding more velocity to it, she will say it is going at (20m/s + 15m/s) 35m/s!
- Now I turn around and start throwing the apples from the rear of the truck, backwards!
    - I will still say that my apples are moving at 15m/s, because from my way of looking at it, that's how fast the apple is moving. The only thing I might say that is different is that it is -15m/s, since even I should be able to notice they are going in the opposite direction now.
    - My friend on the sidewalk will say that the apple is moving at (20m/s + -15m/s) 5m/s!

In each of the above examples, we are really talking about two different people having two different frames of reference while measuring the relative velocity of one object.

Frame of reference: When you are standing on the ground, that is your frame of reference. Anything that you see, watch, or measure will be compared to the reference point of the ground. If I am standing in the back of a moving truck, the truck is now my frame of reference and everything will be measured compared to it.

Relative velocity: In the above examples, each person was measuring the velocity of the apples relative to (compared to) the frame of reference that they were standing in. Relative to a person standing on the sidewalk, the apple may be moving at 10m/s, while for a person in the frame of reference of the truck, the apple is moving at 15m/s relative to him.

Example 2: Sitting at your desk, how fast are you moving?

- Relative to the ground: Zero. You're not moving relative to the frame of reference of the ground.
- Relative to the sun: 2.97e4 m/s! That's a pretty big difference, but since the Earth is orbiting the sun at this speed, an observer standing on the sun (ouch!) would say that you are moving at 2.97e4 m/s.
- Both of these answers are correct in their own frame of reference.

Example 3: You might have even noticed relative velocity while sitting at a red light…

- Have you ever been sitting at a red light with a bus stopped next to you?
- You're kind of daydreaming, looking out the window at the side of the bus, when all of a sudden it feels like your car is rolling backwards!
- Then you realize that it was just the bus moving forwards.
    - Your brain knows that the bus was just sitting there on the road… it became part of the frame of reference of the ground.
    - When your brain saw the bus moving forwards, it had already "decided" that the bus won't move. The only option remaining is that you must be moving backwards.

> DID YOU KNOW?
> Frames of reference and relative motion is actually the reason that people get car sick. Your brain is getting two different sets of information about your body's motion that might not exactly agree with each other; information from your eyes, and information from your inner ear. Some people are more sensitive to these differences, which causes them to feel car sick as they watch the road "whiz" by. If you are prone to getting car sickness, try to look forward at a point far in the distance and stay focused on that.

2-D Relative Motion

One other thing that we will need to keep in mind as we begin to solve these problems is that the components are **mutually independent**.

- This might sound like an oxymoron, since ***mutually*** means together, but ***independent*** means apart.
    - What it means is that the two components are obviously working together (***mutually***), touching head-to-tail and stuff, but they are still measuring separate things (***independent***).
    - If one of the components changes it will not affect the other. For example, if **x** got bigger, **y** would still be the same. Only the **resultant** would change.

A perfect example of this is a boat trying to cross a fast moving river.

- Let's say you point your boat directly **East** across a river that is flowing **North**.
- As your boat moves itself through the water towards the **East**, the river is constantly pushing it to the **North**.
- In the end someone watching from the shore would say that you were moving in a direction roughly **North**-**East** .
- This happens because the two components ***mutually*** work together to give us our resultant.

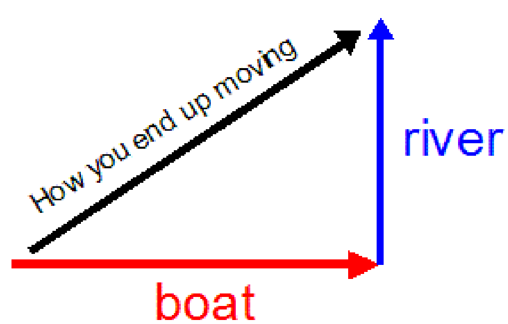


Illustration 1: A boat traveling East across a river flowing North.

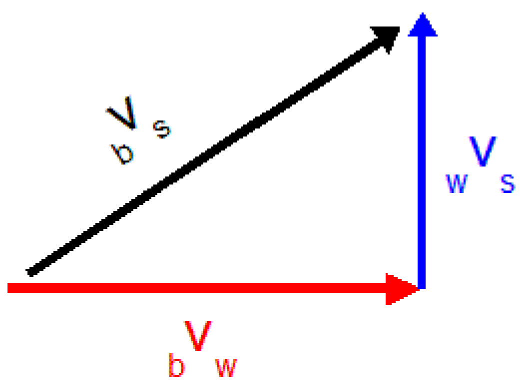
Still, the two components are ***independent*** of each other.

- Let's say you went out and bought a new motor for the boat that could move the boat twice as fast. Do you expect that would change the speed of the water flowing in the river? Of course not. Just because a boat is moving on a river, it does not have an effect on the speed of the river itself.
- What if the motor on the boat stayed the same, but a dam on the river broke and the water started moving faster. This wouldn't change the maximum speed of the motor on the boat.
- In both cases changing one of the components has no effect on the other.

Example 4: You are in a boat that can move in still water at 7.0 m/s. You point your boat directly **East** across a river to get to the other side that is 200 m away. The river is flowing at 4.0 m/s [**N**].

a) **Determine** your velocity measured by someone on the shore.

Calling the vectors "boat" , "river", and "how you end up moving" is not really accurate enough for the kinds of questions we will be looking at in detail. One way to label the vectors with subscripts is shown here, but you may also use any (reasonable) system of your own that you feel comfortable with.



$_{b}\mathbf{v}_{w}$ = velocity of the *boat* in still *water*

$_{w}\mathbf{v}_{s}$ = velocity of the *water* with respect to the *shore*

$_{b}\mathbf{v}_{s}$ = velocity of the *boat* with respect to the *shore*

Illustration 2: Subscripts used to name vectors.

The question is asking for the black vector called $_{b}\mathbf{v}_{s}$, which is the resultant of two components.

$$c^2 = a^2 + b^2$$
$$= 7.0^2 + 4.0^2$$
$$c = 8.0622577 = 8.1 \text{ m/s} = {}_{b}\mathbf{v}_{s}$$

$$\tan\theta = \frac{opp}{adj} = \frac{{}_{w}v_{s}}{{}_{b}v_{w}} = \frac{4.0}{7.0}$$
$$\theta = 29.74488 = 30^{o}$$

The boat is moving at 8.1 m/s [E30°N].

b) **Determine** how much time it takes for the boat to cross the river.

You must choose vectors that point in exactly the same direction to solve questions like this!

Do not be tempted to use your answer from part (a) unless you have good reason to! If you think about it, this boat is going across a river that is 200 m wide measured straight across. Which vector is pointing straight across the river? The red one showing the velocity of the boat as though it was moving in still water. Even though it gets pushed off course by the water, the components are mutually independent! The boat is still moving East across that river at 7.0 m/s. The displacement the boat has to travel (200 m [E]) and the velocity ${}_{b}\mathbf{v}_{w}$ (7.0 m/s [E]) are the only ones that point in exactly the same direction.

$$v=\frac{d}{t}$$
$$t=\frac{d}{v}=\frac{200}{7.0}$$
$$t=28.57142857=29\,s$$

The boat takes 29 s to cross the river.

c) **Determine** how far downstream from directly across the river the boat will hit shore.

Which velocity is pushing the boat downstream? That has to be ${}_{w}\mathbf{v}_{s}$. And from the last question we know how long the boat will be on the water to be able to be pushed downstream.

$$v=\frac{d}{t}$$
$$d=vt=4.0(28.57142857)$$
$$d=114.2857143=1.1e2\,m$$

The boat will hit the shore 1.1e2 m [N] of where it was originally pointed at.

If you look back at the answer for (a) in the previous example, you should probably be able to see how giving you the velocity of 8.1 m/s [E30°N] measured by someone on the shore could be broken into components.

- This way you can figure out the velocity of the water(${}_{w}\mathbf{v}_{s}$) and the velocity of the boat in still water (${}_{b}\mathbf{v}_{w}$).
- You can either put components together to get a resultant, or break a resultant apart to get components depending on your needs.

The other popular type of question to do with components (that is similar to a boat crossing a river) is a plane flying with a wind blowing it off course.

- You will find examples of these types of questions in the worksheet for this chapter.

Homework

p95 #1,2 p97 #2 p99 #1, 3 p100 #1 p101 #1, 6, 8, 9, 11