Lesson 8: Velocity

Two branches in physics examine the motion of objects:
- **Kinematics**: describes the motion of objects, without looking at the cause of the motion (kinematics is the first unit of Physics 20).
- **Dynamics**: relates the motion of objects to the forces which cause them (dynamics is the second unit of Physics 20).

As we work through these two units on kinematics and dynamics (and through the rest of physics) we will discuss two kinds of measurements (quantities):
- **scalar**: scalars have **magnitude** (a number value), but ***no direction.***
  Examples: time, mass, distance. Mass is a great example, since it has a number value (like 58 kg), but we don't give it a direction (like "East").
- **vector**: have magnitude ***and*** direction
  Examples: velocity, force, displacement. Force has a **magnitude** (like 37 N) and a **direction** (like "pushed to the left").

> "**Quantity**" is the root word for "quantitative" measurements. This means you're supposed to get a number answer. A "qualitative" measurement describes qualities of the data, like "the apple is red."

Displacement & Time

In kinematics we need to be able to have a way to describe the motion of the objects we will be studying, whether it's a car or an atom.
- The most basic information you must have to describe the motion of an object is its **displacement**, and the **time** it took to move that far.
- The displacement of an object is always measured from some **reference point** (which is usually "zero", at a location at the start of the motion of the object).
  - Although we use the words "**distance**" and "**displacement**" interchangeably in everyday language, they mean very different things in physics.
    - The **distance** between two objects is scalar, since it doesn't matter which direction you measure it from. e.g. "We are standing 2.3m apart."
    - The **displacement** of an object is a vector, since you have to state the direction the object has traveled. e.g. "The car moved 2.56km east."

The most simple formula for calculating the **displacement** of an object is…

$$\Delta d = d_f - d_i$$

- The Δ symbol is the greek letter "delta" and means "a change in…"
- The subscript "f" and "i" stand for final and initial.
- So, in this formula, we calculate the displacement of an object by taking the final position minus the initial position.

Example 1: A truck is passing a mark on the road that says 300m, and then passes another one 10s later that says 450m. **Determine** the **distance** the truck moved.

$\Delta d = d_f - d_i = 450 - 300 = 150m$

Note: If the example had asked for the *displacement*, we would have to include a direction (like "East") in our answer.

Example 2: You start walking home from school. After walking 1.3 km North, you get a phone call on your cell from your mom asking if you can meet her at the mall. You will have to turn around and walk 2.5 km South. **Determine** your **distance** and **displacement** to get to the mall.

Let's start by looking at a quick sketch of the situation, as shown at right.
- From the school you first walked 1.3 km [N].
- You then turned around and walked 2.5 km [S].

If we want the **distance** you walked, we need to look at all the walking you did, without considering direction.

1.3 km [N]

2.5 km [S]

$d = 1.3 + 2.5 = 3.8$ km

When we look at your **displacement**, we need to consider the direction that you walked. Even though you walked North at first, turning around and walking South canceled out all of your initial movement. When we measure **displacement** we are only where you started and where you finished, not all the stuff in between. We will consider moving North to be positive, and South to be negative.
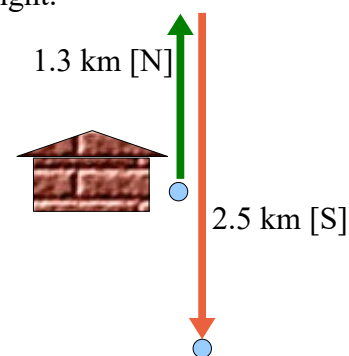
Illustration 1: Walking around after school.

$\vec{d} = {}^+1.3 + {}^-2.5 = {}^-1.2$ km $= 1.2$ km [South]

Notice that the **displacement** is smaller (and negative, meaning South) when compared to your **distance**. That's because even though you actually moved your body around the city 3.8 km, all you really accomplished by the end was moving 1.2 km South of where you started.

Velocity vs Speed

One note for you before we begin to talk about how displacement relates to velocity. Avoid using the word *speed* when describing any **velocity**.
- *Speed* is a *scalar* quantity (it doesn't have direction).
- We usually want the velocity of an object, since velocity is a vector. That means we also know the direction the object is traveling.

What **speed** did you drive today along Yellowhead? ► I drove at 72km/h.
What was your **velocity** along Yellowhead? ► I drove **East** at 72km/h.

Example 3: Look back at Example 2. **Determine** your speed and velocity if the walk took you one hour and ten minutes.

First thing you should do is change the time into seconds.

1 hour = 3600 s ⎱
10 minutes = 600 s ⎰ **4200 s**

I can give myself a bunch of sig digs here. Since I wrote out the time in the question in words, I basically have as many sig digs for the time measurement as I want.

To figure out the **speed**, we need to use the **distance** (in metres!) you traveled in 4200 s. That way we are using only **scalar** measurements.

$$v = \frac{d}{t}$$

$$v = \frac{3.8e3}{4200}$$

$$v = 0.9047619 = 0.90 \, m/s$$

To figure out the **velocity** we need to use the **displacement** you traveled. Now we are using only **vector** measurements.

$$\vec{v} = \frac{\vec{d}}{t}$$

$$\vec{v} = \frac{-1.2e3}{4200}$$

$$\vec{v} = -0.28571429 = -0.29 \, m/sec$$

Average Velocity

This is the first major formula, used for the calculation of **average velocity**.

$$\vec{v}_{ave} = \frac{\Delta \vec{d}}{\Delta t}$$

> When you write the formula, you can skip putting in the arrows you see on the data sheet. They're just there to remind you that those measurements are vectors.

v = velocity (m/s)
d = displacement (m)
t = time (s)

- It is called **average velocity** because it looks at your overall velocity for the entire trip, not at any one particular velocity you might have been traveling at during the trip.
- What you have to measure is the **total displacement** divided by the **total time**.
    - If you drive 275 km to Calgary in 3.00 hours, I calculate your velocity based on this information. The velocity I calculate, 91.7km/h, will be your **average velocity**.
        - I'm looking at the entire trip. It would certainly be rare if you had driven at exactly 91.7km/h every single moment during your drive to Calgary.
        - Sometimes you would have been going faster, sometimes slower, but overall your **average velocity** was 91.7km/h.
    - You basically have to look at the start and finish only, how far did you move from where you started (displacement) in a certain amount of total time.
- These questions can also involve moving at different velocities for different periods of time; we need to be really careful with these questions...

Example 4: I try to run the 100m race to break the world's record. Unfortunately, it takes me 16.83s to complete the run, so I don't think I'll be in the record books. **Determine** my average velocity.

      This is an easy calculation... nothing fancy.

$$v = \frac{d}{t} = \frac{100}{16.83} = 5.941771 = 5.94 \, m/s$$

This is my **average** velocity. It does not show that I have to speed up at the start of the race, or that maybe I was slowing down near the end.

Example 5: A car drives along the highway at 115 km/h for 2.50 h. Once in the city, the car drives at 60.0 km/h for the next 0.500 h. **Determine** the average velocity of the car.

The average velocity is based on the total displacement of the car for the entire time it was moving, so we first need to figure out the total displacement, and then the total time.

Total displacement...

First part of the drive...

$$v = \frac{d}{t}$$
$$d = vt = 115(2.50)$$
$$d = 287.5 \, km$$

Second part of the drive...

$$v = \frac{d}{t}$$
$$d = vt = 60.0(0.500)$$
$$d = 30.0 \, km$$

So, in total, the car moved 317.5 km. We can also see that the ***total time*** driving was 2.50h + 0.500 h = 3.00 h.

The average velocity is...

$$v = \frac{d}{t}$$
$$v = \frac{317.5}{3.00}$$
$$v = 105.8\overline{3} = 106 \, km/h$$

Converting km/h and m/s

In everyday conversation we usually talk about velocity in kilometres per hour (km/h), but need to use metres per second in physics formulas.

- You can **convert km/h to m/s by dividing by 3.6** (this is an exact value and has an infinite number of sig digs).
  - The answer from **Example 5** would be 29.4m/s
- To **convert m/s to km/h multiply by 3.6**
  - The answer from **Example 4** would be 21.4 km/h.
- If you ever do a calculation like this, use the original number on your calculator, not the rounded off answer.

Notice that for most of the examples we've looked at the displacement and the velocity were **positive** numbers.

- **Positive** and **negative** tell you which direction you are going with respect to the reference point. (Remember, these are vectors.)
- A **positive** velocity means you are moving **forward**, to the **right**, or **up**, while **negative** means you are going **backwards**, to the **left**, or **down**.
- This is why it is so important to pay attention to the numbers you are using in your calculations.

Example 6: A train is moving backwards at a velocity of 13.5 km/h for 6.40 minutes. **Determine** the train's displacement.

First we need to make sure we are dealing with standard units, and that the numbers have the correct sign.

$v = -13.50$ km/h $= -3.75$ m/s

$t = 6.40$ minutes $= 384$ s

> To change minutes into seconds, we need to use the ratio of 60s/min. Do **not** change 6.40 minutes to 640s, because that is wrong.

$$v = \frac{d}{t}$$

$$d = vt = -3.75\,(384)$$

$$d = -1440 = -1.44\text{e}3\,m$$

Uniform Motion & Instantaneous Velocity

In many of the questions we will be doing we have to assume that the object is moving at exactly the same velocity the whole time.

- Although this is not very realistic, it makes doing the questions a lot easier.
- For now we will assume that the object is not accelerating at all.
- If the velocity of an object is always the same, we say it has a **constant velocity**. We can also call this **uniform motion**.

You still use the same formula as for average velocity.

- **Uniform motion** is the easiest kind of motion to describe and measure, since it is always the same. If the object is accelerating in any way we have to use different formulas (coming up in Lesson 10).
- In the examples you've done so far, and in most questions you'll do for now, you assume that it is **uniform motion** unless you are told otherwise.

In real life we often have to deal with an object traveling *without* uniform velocity. Things are always speeding up and slowing down.

- Driving in a car you glance down at the speedometer and measure your velocity, but that is only how fast you were going at that instant of time!
- A split second later you might be going a bit faster or a bit slower.
- That's why we call the measurement an **instantaneous velocity**, the velocity of an object at one moment of time.
- It is often easier to measure **instantaneous velocity** if you are looking at a graph of the motion of an object (this also comes up in a later lesson).

Homework

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p.10 #1-3, 7