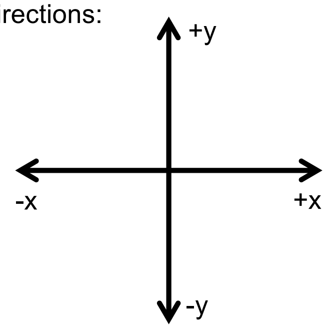
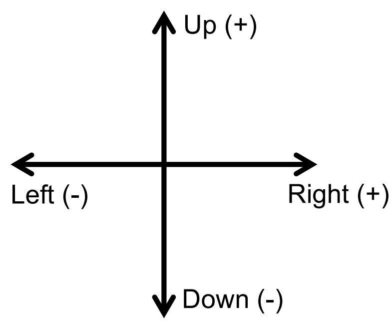
Flipping Physics Lecture Notes:
Introduction to Displacement and the Difference between Displacement and Distance

Displacement:
- The straight-line distance between the initial and final points
- The symbol is Δx, where Δ means “change in” and x means “position”
- The change in position of an object
- $\Delta x = x_f - x_i$ (read, displacement equals position final minus position initial)
- Can be either positive or negative
- Possible dimensions: meters, feet, kilometers, furlongs, rods, ångström, etc (any linear dimension)
    - This number is the Magnitude or amount of the displacement
- Has both magnitude and direction
- Displacement $\neq$ Distance

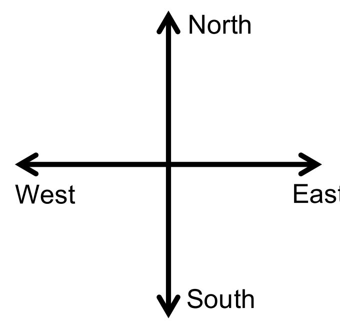
Directions:



Cartesian Coordinates



Relative Directions



Cardinal Directions

The 3 examples are done in the video don’t really need lecture notes.

Flipping Physics Lecture Notes: Introduction to Velocity and Speed

Velocity: Symbol is lowercase v. Equation is: $\boxed{v = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}}$

Velocity has both Magnitude and Direction.

Example problem: Mr.p takes his dog Buster for a walk. If they walk for 27 minutes and travel 1.89 km East, what is their average velocity in meters per second?

Knowns: Δt = 27 minutes, Δx = 1.89 km East, v_{avg} = ?

$$v = \frac{\Delta x}{\Delta t} = \frac{1.89km}{27\min} \times \frac{1000m}{1km} \times \frac{1\min}{60\sec} = 1.1\overline{6} \approx \boxed{1.2\frac{m}{s}East}$$

Speed: $\boxed{speed = \frac{distance}{time}}$

Speed has Magnitude only with no direction

Velocity ≠ Speed just like Displacement ≠ Distance

Flipping Physics Lecture Notes:
Why "Show All Your Work!"?
http://www.flippingphysics.com/show-work.html

I've been a high school physics teacher for more than 2 decades and I require you, my students, to "Show All Your Work!". I often get asked why. Today, I answer that question.

After roughly 5 years of teaching physics, I decided to start making you show more and more of your work. Y'all fought back against it and continue to this day to do so, however, I can tell you that you, my students, understand what you are learning so much better now that you "Show All Your Work!". Let's talk about why.

One of the first things I have you, my students, do is a lab which utilizes very little of what you have learned in the class and honestly, you probably could have done a couple of years ago. The whole purpose of this first lab is to make sure you can "Show All Your Work!". The first question on the lab is to take measurements using an electronic balance and a digital scale to determine the density of a steel sphere in kg/m^3. Here are my solutions:

$$\text{Knowns: } m = 68g, D = 25.3mm \;\&\; r = \frac{D}{2} = \frac{25.3mm}{2} = 12.65mm \;\&\; \rho = ?$$

$$V_{\text{sphere}} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(12.65mm)^3 = 8479.3mm^3$$

$$\rho = \frac{m}{V} = \frac{68g}{8479.3mm^3} = 8.0195 \times 10^{-3}\frac{g}{mm^3}\left(\frac{1kg}{1000g}\right)\left(\frac{1000mm}{1m}\right)^3 = 8019.5\frac{kg}{m^3} \approx 8.0 \times 10^3\frac{kg}{m^3}$$

- I listed the values I measured as my knowns.
- I wrote down the equation relating radius to diameter and used it to determine the radius.
- I wrote down what we are solving for.
- I wrote down the equation for the volume of a sphere, substituted in a number for radius, and wrote down the number, with 5 significant figures, for the volume of the sphere, including units.
- I wrote down the equation for density, substituted in numbers for mass and volume, solved for the density in g/mm^3, converted to kg/m^3, and then rounded to 2 significant figures because the least number of sig figs from our knowns was the mass at 2 sig figs.

Here is a reproduction of solutions I received from students:

$$0.068kg, 12.65mm, \frac{4}{3}\pi(12.65)^3 = 8.02 \times 10^{-3} \;\&\; \frac{0.068}{8.02 \times 10^{-3}} = 8.0 \times 10^{-3} = 8.0x10^3\frac{kg}{m^3}$$

Please notice the following:

- None of the known values are identified.
- The electronic balance measured the mass of the steel sphere in grams; however, the student converted the mass to kg without showing that conversion.
- There is no way to measure the radius of a sphere with a digital scale. First you need to measure the diameter of the sphere, then you can determine its radius.
- The equations for volume and density were never shown.
- The volume of the sphere was rounded even though volume is not an answer and no units for volume were given.
- A conversion is missing: $8.0195 \times 10^{-3} \neq 8.0 \times 10^3$ (and no units were shown)
- The unrounded density is missing.

Before students can turn in their first lab in my class, I require them to go through their solutions to the lab with me so we can discuss how well they did and the whole "Show All Your Work!" thing. With a solution like the above, it is not unusual for students not to be able to describe what they did. With a solution where all the work is shown, you do not have to remember because everything is there!

A few subtle points:

- I often see something like this for a solution for radius from diameter:
    - $$D = 2r = \frac{25.3mm}{2} = 12.65mm$$
        - Notice the middle equal sign is not correct.
    - The following is a correct solution:
    - $$D = 2r \Rightarrow r = \frac{D}{2} = \frac{25.3mm}{2} = 12.65mm$$
    - The essential difference is that, when equations on both sides of the sign are not equal to each other, an arrow symbol is used for separating steps instead of an equal sign. The arrow indicates that one equation can be rearranged to form the next equation.
- I require you to write out an equation right before you use it.
    - "But the equation is written at the top of the page?" is a rebuttal I often hear.
        - There are going to be many, many equations in this class. You absolutely need to get used to showing exactly which one you are using as you use it.
    - Writing an equation out *after* you use it skirts the whole point of writing the equation down in the first place. The reality is that the act of writing out known variables and equations before you use them is a part of the physics thinking process. Usually when you start solving a problem, you do not know what the solution will be. Writing down equations and known values are helpful ways of processing information, will help streamline your thinking, and helps you figure out what the solution is.
        - I am trying to help you build good problem-solving habits for more difficult and longer problems in the future.
- You need to substitute numbers into your equations, even though you have already written those numbers down. This decreases mistakes and illustrates what you actually did.
- Every ending number in your solution must have units.[1,2]
- You need to show conversions. Soooooo many mistakes are made because students incorrectly convert a number. Showing the conversion mitigates these mistakes.
- Always write out the unrounded answer before you round. You are less likely to make mistakes when you do this, and you might need the unrounded number later. (Yes, it is needed later in this lab.)

Another example of part of this solution which I often see from students is the following:

$$r = \frac{D}{2} = \frac{25.3}{2} = 12.65^3\left(\frac{4}{3}\right)\pi = 8479.3mm^3$$

What is usually happening here is that the student has correctly solved for the radius of 0.955 cm, however, they then think, "Oh, I'm solving for volume!" and plug in numbers to solve for volume. This makes this equation no longer correct. A corrected version of this is:

$$r = \frac{D}{2} = \frac{25.3}{2} = 12.65mm \;\;\&\;\; V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(12.65)^3 = 8479.3mm^3$$

This solves for radius, then solves for volume.

So, to answer the question "Why do I require you to 'Show All Your Work!'?", it is to help you learn more efficiently. As you get further and further into your physics learning, the situations you will be analyzing will become more and more complex, and all of the topics will build on one another. This means your solutions will get longer and longer and longer. If you learn how to "Show All Your Work!" at the start of your physics learning, you, and others, will be able to follow your work, you will learn more efficiently, and you will be happier physics students. And that is what I want for you, to be happy physics students. So, please, please, please, "Show All Your Work!"

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[1] Eventually we will get to some numbers which do not have units; however, I'll make that very clear when it occurs!

[2] I do not require units on all numbers in the middle of equations. It gets too cumbersome.

Flipping Physics Lecture Notes: Average Velocity Example Problem with Three Velocities

Example Problem: Buster and mr.p embark on a southward journey. First they walk South at 6.5 km/hr for 1.1 hours. Then they stop to take a nap for 18 minutes and then continue South at 5.5 km/hr for 1.2 hours. (a) What was their average velocity for the whole trip? (b) What was their displacement for the whole trip?

Knowns: $v_1 = 6.5\frac{km}{hr};\ \Delta t_1 = 1.1hr;\ \Delta t_2 = 18\min \times \frac{1hr}{60\min} = 0.3hr;\ v_2 = 0;\ v_3 = 5.5\frac{km}{hr};\ \Delta t_3 = 1.2hr$

(a) v_{total} = ? (b) Δx_{total} = ? (all directions are South)

$$v = \frac{\Delta x}{\Delta t} \Rightarrow (\Delta t)v = \frac{\Delta x}{\Delta t}(\Delta t) \Rightarrow v\Delta t = \Delta x \Rightarrow v_1\Delta t_1 = \Delta x_1 \Rightarrow \Delta x_1 = \left(6.5\frac{km}{hr}\right)(1.1hr) = 7.15km$$

$\Delta x_2 = v_2\Delta t_2 = (0)(0.3) = 0km$ & $\Delta x_3 = v_3\Delta t_3 = \left(5.5\frac{km}{hr}\right)(1.2hr) = 6.6km$

Part	Δt (hr)	v $\left(\frac{km}{hr}\right)$ South	Δx (km)
1	1.1	6.5	7.15
2	0.3	0	0
3	1.2	5.5	6.6

$\Delta x_t = \Delta x_1 + \Delta x_2 + \Delta x_3 = (7.15) + 0 + (6.6) = 13.75 \approx \boxed{14km\,South}$ Answer to Part (b)

Part (a) $\Delta t_t = \Delta t_1 + \Delta t_2 + \Delta t_3 = (1.1) + (0.3) + (1.2) = 2.6hr$

$$v_t = \frac{\Delta x_t}{\Delta t_t} = \frac{13.75km}{2.6hr} = 5.28846 \approx \boxed{5.3\frac{km}{hr}South}$$

Note: $\frac{v_1 + v_2 + v_3}{3} = \frac{7.15 + 0 + 6.6}{3} = 4.58\overline{3} \neq 5.28846 = v_{avg}$

This is only true if each part is for an equal amount of time.

Flipping Physics Lecture Notes:
Example Problem: Velocity and Speed are Different

Example Problem: Buster and mr.p embark on a walk. If they leave mr.p's house, travel a distance of 1.2 km and return back to the house 12 minutes & 13 seconds later, (a) what was their average speed and (b) what was their average velocity? Give answers in meters per second.

Knowns: $distance = 1.2km \times \frac{1000m}{1km} = 1200m; \quad time = 12\min \times \frac{60\sec}{1\min} + 13\sec = 733\sec$

(a) $Speed_{avg}$ = ? & (b) v_{avg} = ?

(a) $speed = \frac{distance}{time} = \frac{1200m}{733\sec} = 1.63711\frac{m}{s} \approx \boxed{1.6\frac{m}{s}}$

(b) $v = \frac{\Delta x}{\Delta t} = \frac{0}{\Delta t} = \boxed{0}$

They started and ended in the same location, therefore the straight-line distance between where they started and ended is zero. Hence, displacement equals zero. Therefore velocity is also zero.

Remember Velocity ≠ Speed and Speed is *not* simply velocity without direction.

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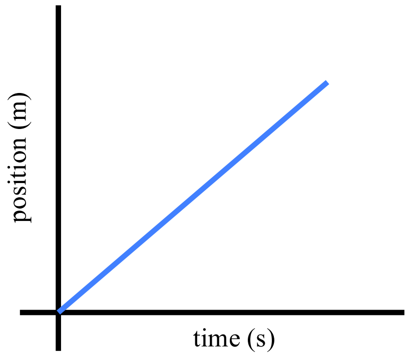
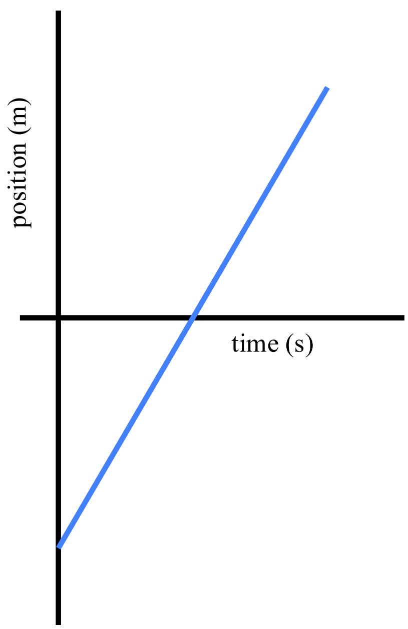
Flipping Physics Lecture Notes:
Understanding, Walking and Graphing Position as a function of Time



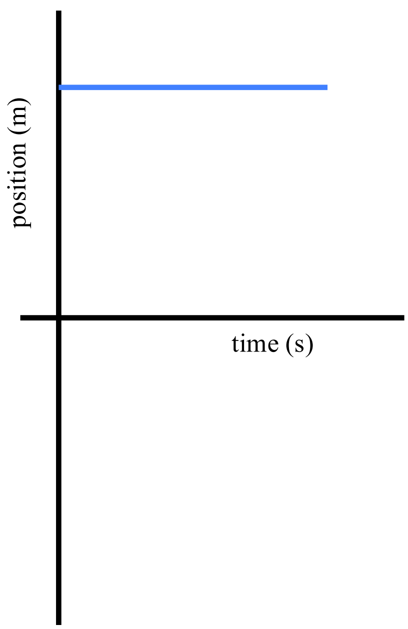
$$slope = m = \frac{rise}{run} = \frac{\Delta y}{\Delta x} = \frac{\Delta position}{\Delta t} = velocity$$

The slope of a position versus time graph is velocity

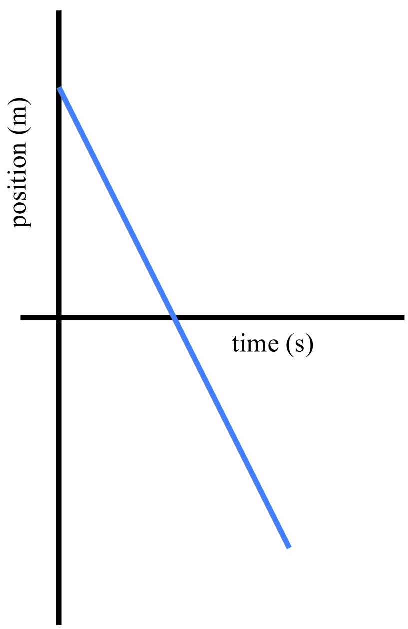
Example #1



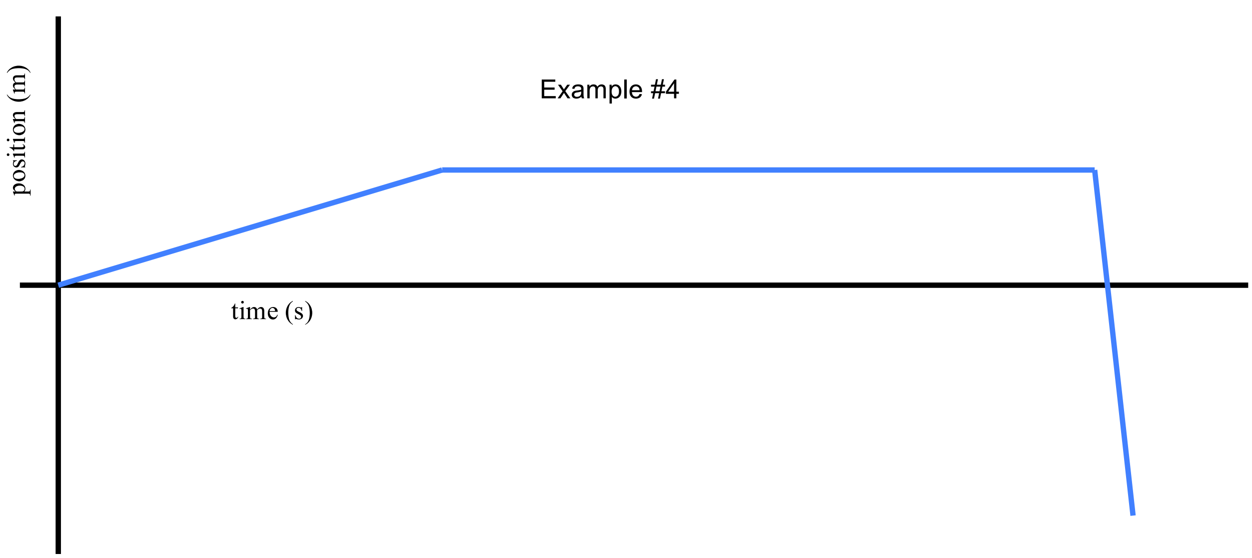
Example #2



Example #3



Example #4



Flipping Physics Lecture Notes:
Example Problem: Finding Average Speed for Pole Position – Not as easy as you think

Example: During the 2010 Indy 500 Hélio Castroneves won pole position by averaging 228.0 miles per hour (mph) for four 2.500 mile laps. If he averaged 222.0 mph for the first 2 laps, what must his average speed have been for the last two laps? (you may assume the number of laps is exact)

Knowns: d_{lap} = 2.500 miles, s_1 = 222.0 mph, s_2 = ?, d_1 = 2 x 2.5 miles d_1 = 5 miles = d_2, s_t = 228.0 mph & d_t = 4 x 2.5 miles = 10 miles

$$Speed = \frac{distance}{time} \Rightarrow s = \frac{d}{t} \Rightarrow s(t) = \left(\frac{d}{t}\right)t \Rightarrow s(t) = d \Rightarrow \frac{s(t)}{s} = \frac{d}{s} \Rightarrow t = \frac{d}{s}$$

$$\Rightarrow t_1 = \frac{d_1}{s_1} = \frac{5}{222} = 0.0.0225225hr \;\&\; t = \frac{d}{s} \Rightarrow \frac{mi}{mi/hr} = \frac{mi}{1} \times \frac{hr}{mi} = hr$$

(flip the guy and multiply!!)

$$\Rightarrow t_t = \frac{d_t}{s_t} = \frac{10}{228} = 0.0438596hr \;\&\; t_t = t_1 + t_2 \Rightarrow t_2 = t_t - t_1 = 0.0438596 - 0.0225225 = 0.0213371hr$$

$$s_2 = \frac{d_2}{t_2} = \frac{5}{0.0213371} = 234.333 \approx 234.3\frac{mi}{hr}$$

Please notice that students will still want to say that:

$$s_t = \frac{s_1 + s_2}{2} \Rightarrow 228 = \frac{222 + s_2}{2} \Rightarrow 228(2) = 222 + s_2 \Rightarrow s_2 = 228(2) - 222 = 234.0\frac{mi}{hr}$$

Which is clearly not true because 234.0 ≠ 234.3 & that $s_t = \frac{s_1 + s_2}{2}$ is only true if the two speeds are for the same *time* not the same distance.

Please note that Castroneves' recorded average speed actually had 6 significant figures and was 227.970, however, we only used 4 significant figures so that it would be easier to show how people incorrectly predict the necessary speed. Also, there is no way that he could average 234 miles per hour for 2 laps, sorry.

Flipping Physics Lecture Notes:
"Pillars of Creation" Explanation for Kate
http://www.flippingphysics.com/pillars-of-creation.html

Pillars of Creation from NASA
http://hubblesite.org/image/3471/news_release/2015-01

I am currently reading *The Disordered Cosmos: A Journey into Dark Matter, Spacetime, and Dreams Deferred* by Chanda Prescod-Weinstein[1] and I got to the part where she talks briefly about the “Pillars of Creation” photo taken by the Hubble Space Telescope. There is a picture of the photo in the book which I showed to my wife. I attempted an impromptu explanation of the photo and pretty much completely failed. I think my wife, who has a degree in opera and social work, essentially said, “I understand all the words you are using, however, when you put them into sentence format, they make absolutely no sense to me.”

Here is my attempt to explain to my wife, Kate, what the Pillars of Creation are. My main goals are to explain where, how far away, how big, and what the Pillars of Creation are.

Starting with, “*Where are they?”*
They are located near the constellation Sagittarius which looks like a teapot. The spout of the teapot points towards the center of our galaxy, the milky way galaxy. The top of the teapot points towards Messier 16 or M16. Inside M16 is the Eagle Nebula. And Inside the Eagle Nebula are the Pillars of Creation.

“How far away are they?”
The answer is roughly 7,000 light-years. That’s it.
The Pillars of Creation are 7,000 light-years away.
Unfortunately, that did not help my wife know how far away they are, and if I am completely honest, doesn’t really give me a good idea of how far away they are either. So, let’s try again.

One light-year is the distance light travels in a year. So, realize a light-year is a distance measurement, not a time measurement. Light travels at roughly 3.00×10^8 meters per second or 186,000 miles per second. The Earth is, on average, roughly 93 million miles from the Sun. That means we can calculate how long it takes, on average, for light to travel from the Sun to the Earth.

$$\text{speed} = \frac{\text{distance}}{\text{time}} \Rightarrow \text{time}_{S \to E} = \frac{\text{distance}}{\text{speed}} = \frac{93{,}000{,}000\text{miles}}{186{,}000\frac{miles}{second}} = 500\text{seconds}$$

$$\Rightarrow \text{time}_{S \to E} = 500\text{seconds}\left(\frac{1\text{minute}}{60\text{seconds}}\right) = 8\frac{1}{3}\text{minutes}$$

But, that evidently was not overly helpful for Kate’s understanding. So, let’s try something different. Let’s determine how far a light-year is in miles. To do that, first we need to determine how many seconds there are in a year.

$$1\text{year}\left(\frac{365.242\text{days}}{1\text{year}}\right)\left(\frac{24\text{hours}}{1\text{day}}\right)\left(\frac{3600\text{seconds}}{1\text{hour}}\right) \approx 31{,}560{,}000\text{seconds}$$

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[1] I definitely recommend reading the book. It is quite good.

$$\text{speed} = \frac{\text{distance}}{\text{time}} \Rightarrow \text{distance} = (\text{speed})\,(\text{time})$$

$$\Rightarrow \text{distance}_{\text{ly}} = \left(186{,}000\frac{miles}{second}\right)(31{,}560{,}000\text{seconds}) \approx 5{,}870{,}000{,}000{,}000\text{miles}$$

Remember that our goal was to figure out how far 7,000 light-years is, the distance to the Pillars of Creation.

$$\Rightarrow (7{,}000)\,\text{distance}_{\text{ly}} = (7{,}000)\,(5{,}870{,}000{,}000{,}000\text{miles}) \approx 41{,}100{,}000{,}000{,}000{,}000\text{miles}$$

$$\Rightarrow \frac{(7{,}000)\left(\text{distance}_{\text{ly}}\right)}{\text{distance}_{S\to E}} = \frac{(7{,}000)\left(5{,}870{,}000{,}000{,}000\text{miles}_{\text{ly}}\right)}{93{,}000{,}000\text{miles}_{S\to E}} \approx 440{,}000{,}000$$

In other words, the Pillars of Creation are 440 million times farther away than the Sun is from the Earth. In summary, it's really, really far away.

But, *"How big are they?"*
The "pillar" on the far left from base to tip is roughly 4 light-years in length. In other words, it takes light four years to travel from the base to the tip of that "pillar", and it's roughly 250,000 times farther than the Sun is from the Earth.

$$\Rightarrow \frac{(4)\left(\text{distance}_{\text{ly}}\right)}{\text{distance}_{S\to E}} = \frac{(4)\left(5{,}870{,}000{,}000{,}000\text{miles}_{\text{ly}}\right)}{93{,}000{,}000\text{miles}_{S\to E}} \approx 250{,}000$$

But, *"What are they?"*
The reason they are called the Pillars of Creation is because:

1) They look like pillars.
2) Stars are created here.

The Pillars of Creation are clouds of hydrogen gas and dust that are clumping together to form stars. However, unfortunately, there is evidence that a supernova, a giant exploding star, occurred 6,000 years ago near the Pillars of Creation and that they have already been destroyed. That's right, it is likely that the Pillars of Creation no longer exist. But, how then is it that we are seeing them?

The Pillars of Creation are roughly 7,000 light-years away.

A light-year is the distance light travels in a year.

That means the light we are currently receiving to see the Pillars of Creation left there 7,000 years ago. We are looking 7,000 years into the past. That means that, roughly 1,000 years from now, we will get to see the Pillars of Creation be destroyed by the supernova. I don't know about you, however, I am definitely going to set a calendar reminder for that one. I'm thinking January 1st, 3001. See you then!

In case you were interested, here are two good articles about the Pillars of Creation:

- *The "Pillars of Creation" Have Been, Are Being, and Will Be Destroyed* from Discover Magazine.
    - https://www.discovermagazine.com/the-sciences/the-pillars-of-creation-have-been-are-being-and-will-be-destroyed
- *The Pillars Of Creation Haven't Been Destroyed, After All* from Forbes
    - https://www.forbes.com/sites/startswithabang/2018/02/21/the-pillars-of-creation-havent-been-destroyed-after-all/