Temperature: Crash Course Physics #20

Crash Course: Physics
https://youtube.com/watch?v=6BHbJ_gBOk0
https://nerdfighteria.info/v/6BHbJ_gBOk0

This episode of Crash Course Physics is sponsored by Audible.

Have you ever taken a good look at your nearest bridge? We already know what can happen to a bridge if you don't consider all the variables before you build one.

But what about the ones that work just fine, like the ones you cross everyday, like on your commute? If you've ever stopped to take a look, you might notice that there are cracks in the concrete. These cracks are a few centimeters thick and they contain what looks like some kind of metal grating. The cracks and grating are there for a reason; there's called expansion joints, and without them the bridges would probably have failed a long time ago. If there are bridges in your town, they probably have expansion joints too.

So, why are these ugly metal cracks necessary? The answer has to do with thermodynamics, the study of temperature and how it affects matter.

Intro

So what is temperature anyway? At the most basic level, temperature is a measure of how much kinetic energy - that ism energy of motion - is in a system. The hotter something is, the higher its temperature, it has more kinetic energy because its atoms and molecules are moving around more.

And the easiest way to figure out if there's a temperature difference between to systems is through heat transfer, the hotter system will always transfer heat to the colder one. And if there's no transfer between systems at all, that's called thermal equilibrium, but usually there will be some heat transfer because that's how the temperature of a system changes.

And when the temperature of an object changes, it can undergo what's known as thermal expansion. Usually an increase in temperature will make a solid expand and a decrease in temperature will make it contract. Now there are two main ways the dimensions of a solid can change based on the change in temperature. It can increase or decrease in length or it can increase or decrease in volume. These changes in length and volume work very similar to the changes in length and volume from stress and strain that we talked about in our episode on statics.

In the case of a bridge, the changes in its length was known as linear expansion, and the equation used to describe linear expansion says that the change in length is equal to what's known as the coefficient of linear expansion times the initial length times the change in temperature. So let's break that equation down to see how it works.

The longer the bridge is to start with, the more it will expand or contract, and the greater the temperature change the more it will also expand or contract. The only other thing that the change in length depends on is the coefficient of linear expansion, represented by the Greek letter alpha. The value of that coefficient depends on the material and the higher the coefficient is, the more the length of the material will change in response to a change in temperature.

And that's why bridges have expansion joints, to give the concrete room to expand when it's warmer outside and contract back down in cooler weather. Without expansion joints the concrete would experience much more stress, and you'd be much more likely to end up with a broken bridge.

And the same principles apply to other kinds of expansions. Volume expansion is just like linear expansion except that the change happens in all three dimensions. The equation for volume expansion just says that the change in volume is equal to the coefficient of volume expansion times the initial volume times the change in temperature. As with linear expansion, the bigger the object is in the first place, the more it'll expand or contract, and a greater temperature change will lead to a greater change in volume. Finally, the volume change depends on how much of a tendency any particular material has to expand and contract, that's its coefficient of volume expansion, represented by the Greek letter beta.

But changes in temperature don't only affect solids. They also affect gasses. And in gasses, temperature has a direct bearing on pressure, volume, and amount of the gas. All four of these properties are related to one another. If you've taken a chemistry course like maybe the one hank hosted, you're probably already familiar with the concept of an ideal gas. A hypothetical gas that obeys a set of rules which lets you describe it more simply. So what are these rules?

Well, an ideal gas is made up of lots of molecules that move around randomly. As they're zooming around, those molecules might collide and bounce off one another, but then exert no other forces on each other outside of these collisions. And the volume of all these gas molecules combined is very small compared to the volume of the container. In many cases a real gas is close enough to an ideal gas that these assumptions apply. Which means that we can use the equations that describe ideal gases to describe the behavior of lots of real life situations, too.

And each of these laws is named after a uniquely awesome individual who lived hundreds of years ago. The first is called Boyle's Law. It says that as you increase the pressure of the gas while holding the temperature constant, the volume of the gas will go down and vice verse. When you increase the pressure you're squeezing the molecules together so they occupy less space.

The second basic law is called Charles' Law. And it says that as you increase the temperature of a gas while holding the pressure constant, the volume of the gas will go up and vice verse. Raising the temperature of the gas gives the molecules more energy which means they can rocket around more forcefully, expanding the size of the container.

So far we've talked about how the properties of an ideal gas relate to each other when you hold the temperature constant and when you hold the pressure constant, so you can probably guess what the third law is for. It's called Gay-Lussac's Law and it says that if you increase the temperature of a gas while holding the volume constant, the pressure of the gas will go up and vice verse. What's happening here is that the increase in temperature again gives the gas molecules more energy and a higher speed, but this time the size of the container is fixed. So the molecules hit the side of the container more often and with more force, increasing the pressure inside.

All three of these laws can be combined into one main equation known simply as the ideal gas law, which also takes into account the amount of the gas. Pressure times volume is equal to the number of moles times R times the temperature, also known as PV=nRT.

The n stands for the number of moles in the gas. A mol is just a unit that's used to measure the amount of a substance, in this case a gas, in terms of the number of molecules. If you have one mol of gas it means that you have 6.02*10^23 molecules of the stuff.

R meanwhile is what's called the universal gas constant. It's a number that connects the pressure and volume of an ideal gas to the number of moles of the gas and it's temperature. And for every

ideal gas, as long as your units are consistency, R will be exactly the same number.

The ideal gas law includes the three basic laws we just talked about: how pressure changes with volume, how temperature changes with volume, and how pressure changes with temperature. But instead of talking about each of those relationships individually, it lets you relate all four properties of a gas, including how much gas you have. To see all of this in action, let's see how the ideal gas law relates to your commute.

Let's say that as part of your daily routine, you drive to school once in the morning and once in the afternoon. It's pretty chilly in your car as you drive in the morning, about 285 degrees Kelvin, and you don't bother to turn on the heat. By the time the afternoon comes along, it's much warmer in your car, about 300 Kelvin, but you don't turn on the air conditioning. What we want to know is how many fewer moles of air there are in your car in the afternoon.

Your car isn't air tight so molecules of air are free to move in and out. We'll say that the volume of the inside of your car where you sit is about 5 meters cubed, and that volume isn't gonna change much. The pressure inside your car is going to be equal to the outside air pressure, which we'll take to be the standard atmospheric air pressure, or 101,325 Pascals. So how many moles of air were inside your car as you drove to class in the morning? Well, according to the ideal gas law, the amount of gas in moles is equal to pressure times volume divided by temperature times the universal gas constant. And 101.325 pascals, times 5 meters cubed, divided by the universal gas constant times 285 degrees Kelvin is about 214 moles. So there are roughly 214 moles of air in your car when you drove to class in the morning.

Now, how many moles were in your car when you drove home in the afternoon, when it was about 15 Kelvin warmer than in the morning? We do the same calculation, just this time with temperature equal to 300 Kelvin, and find that there are only about 203 moles of air in your car in the afternoon. That's a difference of 11 moles! SO there's about 5.2% less air in your car than there was in the morning, just because it got warmer outside.

Today you learned about temperature. We talked about thermal expansion including linear and volume expansion, and we went over the ideal gas law and how to use it to find the number of moles of air in your car.

This episode of CrashCourse Physics is supported by audible.com and right now audible is offering viewers a 30 day trial period. Check out audible.com/CrashCourse to access their audio programs and titles like this one, a Brief History of Time by Stephen Hawking, fascinating stuff that Hawking makes super understandable. Which you know isn't always easy. Actually it's quite difficult at times. So go to audible.com/CrashCourse and make sure you use that link to help us out and for you to get a free membership trial.

CrashCourse Physics is produced in association with PBS Digital Studios. You can head over to their channel and check out a playlist of the latest episodes of shows like First Person, PBS Off Book, and PBS Game/Show. This episode of CrashCourse was filmed at the Dr. Cheryl C. Kinney CrashCourse studio with the help of these amazing people, and our equally amazing graphics team is Thought Cafe.