2640 lumens.

1 foot.

2.3 kilograms.

9 volts. Aaah!

I just closed the circuit with my tongue and I felt all 9 of the volts. So what do all these things have in common? They're units.

Yes, but they're also absolutely, completely arbitrary.

(Intro)

You know who decides how much a kilogram weighs?

A hunk of platinum and iridium known as the International Prototype Kilogram or IPK.

The IPK isn't just how much a kilogram weighs. In a very real sense the IPK is the kilogram. Every other kilogram is exactly the same as the IPK, and the IPK is the lump of metal that decides what that mass is. A kilogram is defined as being the same mass as the IPK. We made kilograms up just like we made up seconds and weeks and volts and newtons.

There's nothing about these things that makes them them.

Someone just decided one day that that was a kilogram.

Now the fact that I find units fascinating probably says more about me then it does about units, but I can talk about them all day.

For example, did you know that the International System of Units only includes seven base units and every other unit is derived from those units? Speed is length divided by time. Acceleration is speed divided by time again, so meters per second per second.

Force is that acceleration multiplied by mass, cause F=ma remember? Work done in joules is force multiplied by distance. And power is work divided by time, so how much work can be done per unit of time. Makes sense.

It goes pretty deep, and it's absolutely correct to say that there are an infinite number of possible derived units, just most of them aren't useful enough to name.

But here's a bit of trivia for you. When I say watts or hertz, those things are just regular words. No special capitalization necessary. But Hertz and Watt, they were real people with like last names that were capitalized.

So what's up with that? Well, getting a unit named after you is kind of the holy grail of science. To quote Richard Hamming: "True greatness is when your name - like hertz and watt - is spelled with a lowercase letter." Of course when these geniuses were first piecing together how the world works they had no idea that there were fundamental basic units beneath it all.

They were basing all of their units on arbitrary values because, well, how could there possibly be a fundamental amount of mass or distance.

Interestingly, one of the standard base units is derived from an actual value though not a universal one. The second is 1/60th of 1/60th of 1/24th of the time it takes for the Earth to rotate a single time. That's something, at least but it also illustrates an interesting point. As fundamental as that seems, when you get down to the dirty details things start to get kind of cloudy.

The Earth's rotation for example is slowing down. Does that mean that seconds should also slow down? No. That would mess up every calculation ever. So seconds are slowly becoming less and less based on reality. Now don't worry. It's gonna take forever for the Earth to slow down noticeably. And when it does we'll just keep adding leap seconds to keep things balanced.

But units are extremely important in chemistry and in sciences in general, as we learned when the Mars Climate Orbiter crashed into Mars because instructions were inputted in the wrong units.

Next time you get a B instead of an A because you didn't keep track of your units, just remember at least you didn't destroy a 300 million dollar mission to Mars. But what do I mean when I say keep track of your units?

Well. I mean watch them. Do not let them do anything you didn't tell them to do because they're sneaky.

And a lot of chemistry is just converting between units. So say you are in a car, and the car is going 60 miles per hour. Now right now everyone who doesn't live in America is like: "Boo, miles are terrible. Convert to kilometers Hank!"

Well I'll do you one better. From a scientific perspective, kilometers are terrible too. They're just as arbitrary. We should use something more universal. Like light-years. The amount of distance light can travel in a year. And hours, hours is no fun.

So let's convert to light-years per second. 60 miles per hour. When you say it it sounds like a whole number with a single unit. But it's not. It's actually a fraction. 60 miles over 1 hour. Let's start with the easy part. Getting to the seconds.

So first we've got to get to minutes. So there's 60 minutes per hour. And also 1 hour per 60 minutes. That fraction once we have it can flip either way. We want it with the hours on the top, on the numerator. Why?

Because we want the units to cancel. We want to destroy the hours. We don't want them in our units when we're done. And then the same thing happens again with 1 minute per 60 seconds. Now we go to light-years.

I asked Google, and there's 1 light-year in every 5.9×10^{12} miles. Looking at this we see that the hours cancel and the minutes cancel and the miles cancel. Leaving us with light-years per second. That's really what matters.

We've come out with the correct units. The rest is just hammering at the calculator to discover that a car going 60 mph is also going 9.3×10^{-12} light-years per second.

Now we perform an important test. The "does this make sense?" test. And yes indeed it does because 9.3×10^{-12} is a very, very, very, very small number. Which makes sense because when you're traveling in a car you're going a very, very, very, very, very, very, very tiny fraction of a light-year every second.

Now there are probably gonna be fifty to a hundred thousand people that watch this video. And I'm gonna guess that maybe a solid seven of you did the math along with me with your calculator out. Now I'm not giving you a hard time. That's just my guess.

If you want to follow along with your calculator in the future that might be helpful. It would at very least be very nerdy. But if you have been following along with your calculator, you might maybe have noticed something interesting. I said 9.3×10^{-12}. When your calculator...

Your calculator probably said something like $9.3487658140029 \times 10^{-12}$. So why, when I had so many more numbers to give, did I only give two? Was I trying to save time? Well obviously not, because now I appear to be wasting time talking about it. Do you think that it would be too hard for me to remember all those numbers? Well obviously not, because I just did it. So I will tell you why.

When you're doing experimental calculations, there's two kinds of numbers. There's exact and measured. Exact numbers are like the number of seconds in a minute or the number of eggs in a dozen. They're defined that way and thus we know them in effect all the way out to an infinite number of decimal places. If I say that there are a dozen eggs you know that that's 12. It's not 12.0000000001 or 11.9999999. It's 12.

But that's not true for the number of miles per hour my car was going. That car wasn't going 60.0000-out into infinity mph. I only know the speed of my car to two decimal places because that's all I get from the speedometer. So the car could have been going 59.87390039 mph or 60.49321289 mph; the speedometer would still say 60.

And no matter how well I measure the car's speed, I will never know it at the same level of precision that I know the number of eggs in a dozen. So that's the second type of number, measured numbers. Now the cool thing about measured numbers, because you never ever know them exactly, is that they tell you two things at once.

First, they tell you the number that was measured. And second, they tell you the precision at which that number was measured. People often get their heads all tangled up about this, but with a measured number you just have to remember that the actual number goes out to infinite decimal places, you just never know all of them. You can't. It's impossible, so when my scale says 175 lbs, that doesn't mean 175.000000 lbs. It means 175.something lbs.

And all those numbers after the five? We don't know them. And here's the thing, a measured number can be pretty unhelpful if you don't have knowledge of the precision of the measurement. So you have to conserve the precision through your calculations or else you might end up killing someone with an imprecise dose of insulin or something.

So we have a set of rules for what are called significant figures: these are the digits in your number that you actually know. With my speedometer there are two: 6 and 0. But 0 is weird, because sometimes it's just used as a placeholder. Like if I said that the fastest plane can go 13,000 mph, which it can by the way.

An unmanned military test glider did it in 2011. That's not an exact number, those zeroes are just placeholders. So when a number ends in a zero, or two or three zeroes, it's hard to tell if those zeroes are significant. But this all gets so much simpler when you use scientific notation, which since it's science we should. So 60 mph would instead be 6.0×10^1. We get that zero is significant because we wrote it.

Otherwise it would just be 6×10^1. We keep that zero around because we actually know it. Scientific notation is awesome by the way, once you get the hang of it. If you're having trouble you can always just type it into Google or your calculator to see exactly what number we're talking about, but the number of the exponent just tells you how many places to move the decimal point.

So to the 1st power you move it one to the right and you get 60. To the negative 1st power you move the decimal point one place to the left and you get 0.60. To the fifth power, one, two, three, four, five, and you get six with five zeroes or 600,000. Of course your significant figures get preserved, so 2.4590×10^{-4} is 0.00024590 and you still get the same five sig figs.

Now to the magic of figuring out how many sig figs your answer should have. There are two simple rules for this. If it's addition or subtraction it's only the number of figures after the decimal point that matters. The number with the fewest figures after the decimal point decides how many figures you can have after the decimal in your answer. So 1,495.2+1.9903 you do the math.

First you get 1,497.1903 and then you round to the first decimal, because that first number only had one figure after the decimal. So you get 1,497.2. And for multiplication just make sure the answer has the same sig figs as your least precise measurement.

So $60 \times 5.0839 = 305.034$, but we only know two sig figs so everything after those first two numbers is zeroes: 300. Of course then we'd have to point out to everyone that the second zero but not the third is significant so we'd write it out with scientific notation: 3.0×10^2. Because science!

Now I know it feels counterintuitive not to show all of the numbers that you have at your fingertips, but you've got to realize: all of those numbers beyond the number of sig figs you have? They're lies. They're big lying numbers. You don't know those numbers. And if you write them down people will assume that you do know those numbers. And you will have lied to them. And do you know what we do with liars in chemistry? We kill them!

Thank you for watching this episode of Crash Course Chemistry. Today you learned some keys to understanding the mathematics of chemistry, and you want to remember this episode in case you get caught up later down the road:

How to convert between units is a skill that you'll use even when you're not doing chemistry.

Scientific notation will always make you look like you know what you're talking about.

Being able to chastise people for using the wrong number of significant digits is basically math's equivalent of being a grammar Nazi.

So enjoy these new powers I have bestowed upon you, and we'll see you next time.

Crash Course Chemistry was filmed, edited, and directed by Nick Jenkins. This episode was written by me, Michael Aranda is our sound designer, and our graphics team is Thought Bubble. If you have any questions, comments or ideas for us, we are always down in the comments. Thank you for watching Crash Course Chemistry.