

An Introduction to Matter and Measurement

Scientific Measurement

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If I were going to explain American football to my friend from someplace who doesn't understand American football, and I said that the distance from end zone to end zone was 100, what would be the problem with that? Well, the answer is I haven't associated any units with the 100. Is it 100 inches? Is it 100 miles? Is it 100 feet? So the problem is that whenever you describe any sort of measurement in science, or in real life for that matter, what you have to do is you always have to associate units with the measurement. Units have to go with the measurement. So let's explore some units of length, just for grins, and then we'll see why it might be necessary to settle on one unit when we're doing scientific stuff.

Feet, for instance, is a very old unit of length and it probably started out as the length of somebody's foot. Inches is one-twelfth of a foot. Meters is what we're going to come back to. Miles, you know, is 5,280 feet. Cubits, maybe you've never heard of a cubit. Believe it or not, a cubit is the distance from your elbow to the tip of your finger. It's about 18 inches. And, obviously, it's going to depend on whose hand, whose arm. Don't know whose it was, but the point is that a cubit is a fairly convenient unit in the sense that everybody's got one. And so roughly speaking, it's going to be the same. As far as I know, nobody still uses cubits. On the other hand, the next unit, hands, believe it or not, someone actually still uses a hand. What is hand? A hand is the width of Henry VIII's hand. And it's about 4 inches. Well, people who raise racehorses still use the term hands when describing how tall the horse is. It's from the ground up to its withers, which is about its shoulder, and a typical horse is about 15 hands. People whose race horses also use furlongs. A furlong is 220 yards. Light year is something that astronomers use. It's how far light travels in one year. And a parsec is 3.26 light years, but I don't know why we need two lengths that are both quite large. People who do deep sea diving or who go down in submarines use things like fathoms and leagues.

So there are just a plethora of lengths, or units of length that all these different civilizations have come up with. And the problem with having all these different units in science is a very international effort. People in all these different countries are doing science, and if they just reported all their numbers in the unit that they happen to use in their country, then people would constantly be having to convert from inches to meters, and furlongs to parsecs, and blah, blah, blah, and it would just be too much trouble. And so what scientists decided to do was to settle on a set of units that everybody could agree on and everybody would report their data, all their measurements, with a set of units. And that set of units goes by the name SI, and SI stands for *Système International d'Unités*, which is French, and pardon my French, but basically the international system of units. And there are actually only seven base units in the SI system, length, and the unit of length is the meter. And for those of you who might not know, a meter is about 39 inches. Mass is the kilogram, which is about 2.2 pounds. Time is the second, you know that. Temperature is the Kelvin, and you're unfamiliar with the Kelvin at this point. Chemical amount is the mole, and you're unfamiliar with the mole. Electric current is the ampere, something you've probably heard before. And luminous intensity is the candela, and these quantities have these abbreviations here.

Right now, you're probably only familiar with length, mass and time. And that's fine. We'll clarify all these other things for you later on.

Now, there are some derived SI units, units that are just combinations of the original seven, but that have special names as well. For instance, the unit of energy, which we'll come to when we do thermochemistry, is the joule, has the abbreviation J, and it's a kilogram meter squared per second squared. And notice that the exponent has a minus 2. That means it's in the denominator of this expression. A force not so important for chemists is the Newton. Power is the watt. Light bulbs, how much power they consume is measured in watts. Pressure is the Pascal, something you've probably never heard of before, and electric charge and electric potential difference, things that aren't going to be really very important for chemists, but here they are. When you take physics, these are the kinds of things you're going to need to know.

Now, since it isn't necessarily convenient to always express things in the SI units, because they are, for instance, very large, the unit of length is a meter, but not a lot of things in the chemistry lab are this long, we need to have prefixes that allow us to make units that are smaller for convenience. So on top of the SI units, we have the fractions, and these are the ones that you should probably commit to memory. 10^{-2} goes by the prefix centi. The symbol is lowercase "c". For example, c, lowercase c, lowercase m is a centimeter. I'm sure you already know what a centimeter is, but it's one-one hundredth of a meter. 10^{-3} is milli, lower case "m", milliliter. I haven't told you what a liter is, but a milliliter is one-one thousandth of a liter. 10^{-12} is pico, relatively less important, but it turns out that when we're talking about the size of an atom, a picometer is a useful size. It's 10^{-12} meters. And then, going the other way, larger, kilo, 10^3 is a kilo, lowercase "k" is the symbol. Kilogram again is the SI unit of mass, but a kilometer, so

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we change the emphasis on how we pronounce it. Some people say kilometer, but the point is that's one thousand meters.

Now, there are some derived units from the SI system that don't involve special names, like velocity is in meters per second, and so "m" is the unit of length. That's the meter, and the unit of time is a second. Volume, the unit of volume is a cubic meter, and that's a really big thing. It's something that's about a yard on a side, so it's going to be this gigantic thing. And we're going to see that chemists have another unit that's a little more convenient. Density is the mass of an object divided by the volume that it occupies, so the SI unit is kilogram per cubic meter. The rate of reaction, we're going to see much later on, is, in SI units, the mole per cubic meter per second. And again, chemists choose some more convenient units. Again, a cubic meter is not really convenient, because it's big, so chemists talk about things in terms of liters, where a liter is one-one thousandth of a cubic meter. And for those of you who might not know, a liter is about the size of a quart. So a milk carton is about a liter, a unit of mass that, for chemists, is a little more convenient. Chemists don't measure typically things around the neighborhood of 2.2 pounds, which is what a kilogram is, so we use one-one thousandth of a kilogram, which is just the gram. Thermometers are not typically calibrated in Kelvins, they're calibrated in degrees Celsius, and degrees Celsius is the scale that we'll use most often, and I'll explain how you get from degrees Celsius to Kelvins later on. And finally, pressure, the unit that chemists often use is the atmosphere for largely historical reasons, and its related to the SI unit by 101,325 Pascals, which is the SI unit, is equal to 1 atmosphere.

Okay, so given that we sort of tweak the system a little bit as chemists to come up with units that are a little more convenient, what you're going to see is that when we're talking about volume, very often, instead of cubic meters, we're going to be in cubic centimeters. A cubic centimeter is about the volume of the end of your thumb. For density, instead of kilograms per cubic meter, grams per cubic centimeter is going to be much more likely. And similarly, for rates of reaction, since the cubic meter is so large, most often this will be expressed as moles per liter, per second.

What's the bottom line? The bottom line is if you're going to make a measurement, you have to associate units with it. If you're going to report a measurement, you have to associate units with it. And here's something to think about. If your friend from Europe came over to the United States and went to get a haircut and asked the stylist or the barber to cut three off, meaning three centimeters, that would be about an inch. But, in the United States, if you say, "three, cut three off", the barber or stylist is most likely to think three inches. And so the person from Europe is going to lose about three times as much hair as he or she intended to lose. So again, it's really important to associate units with your measurements.