

Chapter 2: Takin' Data



Actor Brent Spiner played the character of Data in “Star Trek: The Next Generation” and in several other Star Trek movies. By all accounts, he’s a pretty nice guy.

http://commons.wikimedia.org/wiki/File:Brent_Spiner_by_Gage_Skidmore.jpg

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Chapter 2: Takin' Data

As scientists, we take a lot of data. Some of these data are good, and some of them are lousy. However, we take data anyway, because otherwise people will take away our funding and we'll have to get real jobs for a change.

Grammar Corner

The word "data" is plural, so it's more appropriate to say "these data" than "this data." Though we'll be using this correctly in this book, keep in mind that anybody who makes a big deal about this is probably a jerk.

Section 2.1: SI Units

When we measure stuff, we always need a unit after our measurement so that we know what we're talking about. For example, if I say that my dog is "1,000" without a unit after it, you wouldn't know for sure whether my dog weighs 1,000 grams, 1,000 ounces, or 1,000 pounds. Come to think of it, it'd be pretty awesome to have a thousand pound dog.

The system of units that scientists use is called the SI system, where "SI" stands for "International System" as spelled in French. As spelled in English, it's "International System."



Figure 2.1: Delicious French bread, another cool thing that the French have given us.

http://commons.wikimedia.org/wiki/File:French_bread_photo.jpg

There are seven¹ **base units** in the SI system that all other units are derived from. They are, in no particular order:

- **Second (s):** This is used to measure time. One second is roughly the amount of time it takes for your mom to get mad when she finds out that you borrowed her car without asking.
- **Meter (m):** This is used to measure distance. One meter is pretty close to a yard, so just pretend like they're the same thing.
- **Kilogram (kg):** This is used to measure mass. Three cans of Mr. Pibb weigh about a kilogram.
- **Kelvin (K):** This measures temperature. We also like degrees Celsius a lot,² but it's not the official unit in the SI universe.

¹ I've only mentioned five of the seven base units, because you don't really need to know much about the ampere or candela in chemistry class.

² Even though we Americans don't really understand these units, either.

- **Mole (mol):** This measures the amount of stuff present. Everybody always likes to make jokes comparing moles (the unit) to moles (the animal), but I'm not going to go there because those jokes are stupid.³

In addition to the base units, there are also about a bazillion units derived from the base units to keep track of. These derived units are called **derived units**. The most common derived unit is the liter (L) which is used to measure volume⁴. Two liters has the same volume as a two liter bottle. Degrees Celsius is another common derived unit. To find it, subtract 273 from the temperature in Kelvin.

Random Thing You're Stuck Learning

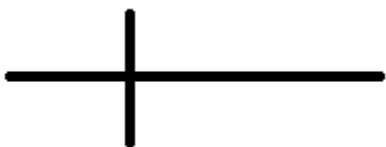
In most chemistry books, they talk about density in this chapter. Density is equal to the mass of something divided by its volume. Enjoy the equation!

Section 2.2: Converting Units

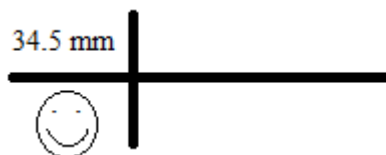
Because we, as Americans, don't use the metric system, we need some handy way of converting our awesome American units to the units that the rest of the world uses.⁵ Let's convert 34.5 mm to m.

Here's how to do this⁶:

- 1) Make a t



- 2) Put whatever you're trying to convert in the top left of the t. Put a smiley face in the bottom left of the t.⁷



³ These jokes are made by the kind of teacher who wears a periodic table t-shirt on Fridays.

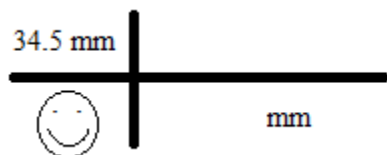
⁴ 1 liter is equal to 1 dm³, which is why it's a derived unit.

⁵ Actually, the metric system is way better than Imperial units, but I try to support America whenever possible.

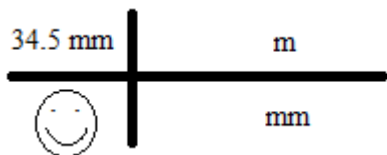
⁶ This will come in handy later in the book, too, so you might as well learn it really well right now to save yourself a lot of trouble. I know that some of you think that you're really good at converting units some other way, but you're wrong, so do it this way instead.

⁷ There is no particular reason this needs doing, except that it makes the t-chart happier looking.

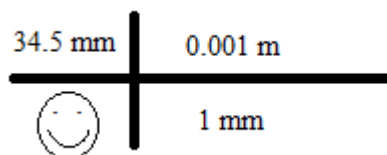
- 3) Put the units of whatever is in the top left in the bottom right box.



- 4) Put the units of what you want to find in the top right box.



- 5) Add a conversion factor that converts the two units you're working with. If you're converting between two metric units, this conversion factor consists of a "1" before the thing with the metric prefix and whatever the prefix means in front of the other unit. For example, the conversion factor between kilograms and grams is 1,000, because the prefix means 1,000:



A Look At The Metric Prefixes

Some of you might not know the metric prefixes. Because only some of them are really important in chemistry, I'm only going to give you the ones that are actually used:

Mega (M) = 10^6 (one million)

Kilo (k) = 10^3 (one thousand)

Centi (c) = 10^{-2} (one hundredth)

Milli (m) = 10^{-3} (one thousandth)

Micro (μ) = 10^{-6} (one millionth)

Nano (n) = 10^{-9} (one billionth)

- 6) Multiply the numbers on the top by each other, then divide by the product of the numbers on the bottom. When you cancel out the units, you should have your answer:

$$\frac{34.5 \cancel{\text{mm}}}{1 \cancel{\text{mm}}} \times \frac{0.001 \text{ m}}{1} = 0.0345 \text{ m}$$

A Handy Tip:

In some cases, you may have to convert more than once. For example, if you're converting from mg to ng, you'll need to convert mg to grams, followed by another conversion from grams to ng.

Section 2.3: Accuracy and Precision

When scientists take measurements, we usually don't have any idea if they're right. I mean, they might be right, but if our equipment is broken, we might get some really lousy measurements instead.

This is where the idea of accuracy and precision come in:

- **Accuracy** is a measure of how close your measured value is to the actual value. For example, if your sister actually weighs 255 pounds and you measured her weight as 253 pounds, you got a pretty accurate answer.
- **Precision** is a measure of how reproducibly you get the same answer if you measure something a bunch of times. For example, if you weigh your sister repeatedly and find that she weighs 235 lbs, 234 lbs, 236 lbs, and 234 lbs, you have precise measurements because you got roughly the same number each times. Note, however, that these measurements aren't accurate, because they're not close to the actual value of your sister.

Why do we care about accuracy and precision? Well, since we can never figure out how accurate a measurement is⁸, we're stuck with precision, which we can verify. Though precise measurements are sometimes horribly inaccurate, we usually assume that precise data is also pretty accurate. Otherwise, why would the guy who made the equipment bother making it precise in the first place?

The error in a measurement is defined by the following equation:

$$\text{percent error} = \frac{\text{error in measured value}}{\text{actual value of thing measured}} \times 100$$

⁸ After all, if we already knew the answer, we wouldn't need to take any measurements.

Though this equation is theoretically easy to work with, I want to point that since we probably don't know the actual value we're measuring, it's pretty tough to find out how big our error is.

Section 2.4: Significant Figures

The precision of a measuring tool is determined by the number of useful digits it gives us when we use it to take a measurement. These useful digits are called **significant figures** (often abbreviated "sig figs"), and though they drive students crazy, they actually come in pretty handy in the experimental world.

Let's consider three measurements: 100 kg, 100. kg, and 100.0 kg. Though these numbers mean the same thing to your calculator and some of your other teachers⁹, they don't mean the same thing to us:

- The value 100 kg has one significant figure, the "1" in the front of the number. Since it's in the hundreds place, this means that our measurement is precise to the nearest 100 kg.
- The value 100. kg has three significant figures (all of the digits shown). Since the last significant figure is in the ones place, this means that our measurement is precise to the nearest kg.
- The value 100.0 kg has four significant figures (all of the digits). Since the last significant figure is in the tenths place, this means that our measurement is precise to the nearest tenth of a kg.

Of course, I haven't yet told you how to figure out which figures in a measured number¹⁰ are significant yet. Here are the rules you need to know:

- Any nonzero digit is significant. For example, all of the digits in the number 325 kg are significant, meaning that the answer is precise to the nearest kg.
- Any zeros that are between nonzero digits are also significant. For example, all of the digits in the number 305 kg are significant, meaning that the answer is precise to the nearest kg.
- All zeros to the right of all the nonzero numbers are not significant. In the case above where I mentioned "100 kg", this means that only the 1 is significant and that the answer is precise only to that decimal place (the hundreds).
- Zeros to the left of all the nonzero numbers are not considered significant. If you see the number 0.001 grams, the zeros at the left are more or less arbitrarily said to be non-significant, leaving us with only the 1 as a significant digit. This makes our value precise only to the thousandth place.

⁹ Physics and math teachers usually aren't very good about significant figures for some reason. Whenever you can, however, correct them on their sig figs. It'll drive them nuts, and there's no good way they can tell you to shut up.

¹⁰ The key idea here is "measured value." Significant figures don't exist for isolated numbers – only for measured numbers – this is because they tell you not how good the data are, but how good the measuring instrument is. If you count a number of something, this is assumed to have an infinite number of sig figs (you can't have 1.02 of a cat).

- Zeros to the right of all the nonzero numbers are significant if you see a decimal actually written out.¹¹ 100.0 grams has four significant figures (all of the digits) and is precise to the nearest tenth of a gram.
- Counting numbers are considered to have infinite significant figures. After all, if the neighborhood loser has a party and throws 6 beer bottles on your front lawn, there are *exactly* six beer bottles there – the number hasn't been rounded at all.

How To Take Measurements

Though you think you're a smart person, you probably don't know how to read a ruler correctly. Because taking measurements is kind of an important thing in science, here are some rules that you should follow when taking measurements on various equipment:

- *For digital equipment (the type that shows you the numbers on a little screen), just write down whatever it says. For example, if the numbers say "0.23 grams", you should record "0.23 grams" as your data.*
- *For analog equipment (it's got some sort of scale with lines on it that you have to figure out for yourself), write down the answer you directly get from the equipment and add one digit that you estimate. For example, if you have a ruler that has lines on it measuring down to the millimeter, you should record the length of something to the nearest tenth of a millimeter, where you estimated the last value.*

When doing calculations with experimental data, it's important that we keep track of significant figures, too. After all, let's consider the case where we find the density of a piece of Styrofoam that has a mass of 1 gram and a volume of 9 mL. Now, the precision on each of these numbers is lousy, but if we find the density (M/V), we find it to be 0.1111111111 g/mL¹². By ignoring significant figures, we've turned lousy data into an unbelievably precise answer. This isn't too cool.

Because calculations are super important in the world of chemistry, let's figure out how to do this using the correct significant figures:¹³

- **Addition and subtraction:** Round your answer to the least precise decimal place of the value you're doing a calculation with. For example, 0.55 g is precise to the nearest hundredth of a gram while 0.224 g is precise to the nearest thousandth. When you add them up to get the answer of 0.774 grams, we have to round our answer to the nearest hundredth to reflect the fact that the 0.55 g is precise only to the nearest hundredth. Our answer, 0.77 grams.

¹¹ In other words, you actually need to see a dot explicitly written out.

¹² If you ever write that little line over the last digit that means "repeating", your chemistry teacher will smack you in the head. After all, that implies infinite precision.

¹³ There are sig fig rules for other mathematical operations, such as logarithms and other stuff I don't really understand. However, in an introductory chemistry class, you're not going to bump into them, so don't sweat it.

- Multiplication and division: Find the number of significant figures for each number, and then write the answer so that it has the same sig figs as the least precise value. For example, if you divide 1.000 grams by 9 mL, you'll get an answer of 0.1 g/mL, which reflects the fact that 9 mL has only one significant figure.

Great Men Of Science



Figure 2.2: King Gustav III of Sweden was known, among other great accomplishments, for coming up with a Swedish national costume that was to be worn by royalty. As far as I know, the guy didn't actually have anything to do with science, but I thought it was pretty cool anyway.

http://commons.wikimedia.org/wiki/File:Gustav_III_of_Swede.jpg

Section 2.5: Graphing stuff

Sometimes, scientists like to graph stuff. Not only does it help us to figure out what's going on with our data, but it also allows us to make our presentations look way cooler. And, as we all know, cooler presentations lead to more funding.

When making graphs in science, always use a line graph. There are other kinds of graphs out there, but we don't use them much in chemistry.¹⁴

To make a good line graph, you need to follow these rules:

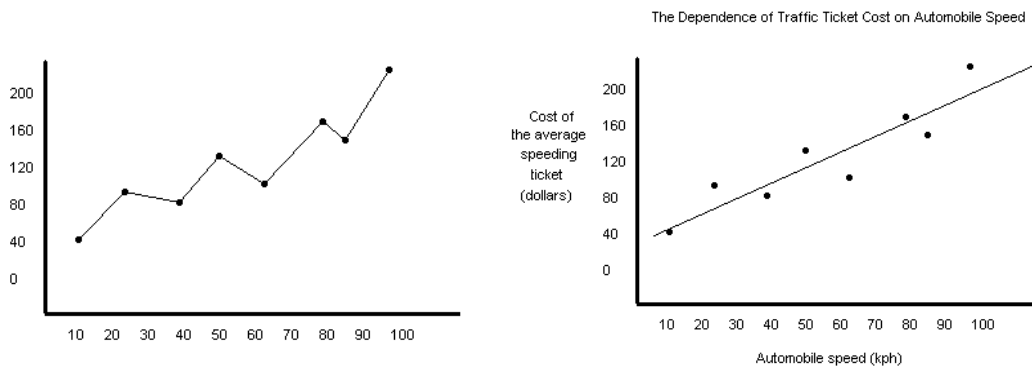
- Give it a title. A good title is "The dependence of [the dependent variable] on [the independent variable]."¹⁵
- The x-axis is always the independent variable and the y-axis is always the dependent variable. Make sure you label both axes with units so people know what they're looking at.
- Don't connect the dots. A graph is meant to be both a descriptive tool (i.e. it tells you what happened) and a predictive tool (i.e. it allows you to predict what will happen). If you connect the dots, you lose the predictive part. It's always good to make either a best fit line or a smooth curve when graphing data.

¹⁴ If you want to use a pie chart, go work for *USA Today*. If you want to use a bar graph, become an economist or something.

¹⁵ For the record, if "time" is one of your variables, it's *always* the independent variable.

- If you see a discontinuity in your graph, this means that something interesting happened. If we were to graph my grandmother's weight versus the year, we'd find that her weight stayed relatively constant, and then dropped dramatically from 2010 onward. This suggests that something interesting happened to her in 2010 that caused a sudden and significant weight loss.¹⁶

Here are examples of good and bad graphs, so you know what to look for:



Chapter Summary

- French people came up with the units we use today. They're called "SI Units", which is short for something French.
- Density is a big deal in a lot of chemistry books. What's up with that?
- Unit conversions aren't really that hard, as long as you use that method in Section 2.2. If you don't use that method, you're on your own, dude.
- Accuracy and precision aren't the same thing, so quit saying that.
- Significant figures tell you how precise your data are. They don't say anything about how accurate your data are, though, so quit saying that.
- When you graph your data, don't make dumb looking graphs.

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¹⁶ She died.