

## Significant figures:

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One of the most baffling things that chemistry students run into is the concept of the significant figure. After all, who cares if you write a number as “100 grams” or “100.0 grams”? Your calculator doesn't know the difference, so why should you worry about it?

There are good reasons that you should be concerned with the number of digits that a number has. In this tutorial, we'll attempt to explain them, as well as give you tips as to how you can master the finer points of significant figures.

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### Why do we need significant figures?

For some reason, teachers hardly ever tell students about why they should be concerned with significant figures. I'm guessing that this is because most teachers haven't really thought about it. They may know what significant figures are and how to find them, but not know why we'd care.

Here's the answer: *Significant figures help you to understand how precise your data are.*

That's it. Let's explain what I mean with three numbers: “100 grams”, “100. grams”, and “100.0 grams.”

- The value “100 grams” indicates that the instrument you used to take the measurement could only take data to the nearest hundred grams. As a result, objects weighing both 55 grams and 130 grams will both read “100 grams” on the balance.
- The value “100. grams” indicates that the instrument could take data to the nearest gram. If such an instrument says “100. grams”, the actual answer must be between 99.5 and 100.4 grams.
- If you see “100.0 grams”, your instrument is taking measurements to the nearest 0.1 grams. In this case, the actual weight of the object is measured to be between 99.95 and 100.49 grams.

That's why significant figures are important: They tell you whether your instrument is measuring to a lot of decimal places or just to a few.

When working with significant figures, never write too many because if you do, your data will show that you've got amazing super-duper precision even though you don't. And if you don't write enough, your data will show that your measurements aren't as precise as you really are. The biggest rule of science is to tell the truth, and significant figures make sure you do that.

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## Accuracy vs. precision

Significant figures tell you how precise a measured value is. A measurement of “430 grams” is precise to the nearest ten grams, as indicated by significant figures.

- **Precision** is a measurement of how reproducible an answer is with some piece of equipment. If an instrument is precise, it will give you an answer that’s more detailed than one that is not because it’s assumed that the instrument will give you the same answer each time.
- **Accuracy** is a measurement of how correct a measured value is. If something weighs 150 grams and you measure the weight as 130 grams, it’s not a very accurate measurement.

Some fine points that need discussing:

- *Precise measurements don’t need to be accurate.* If I were to staple a squirrel to my bathroom scale, I would get the same answer every time I stood on it (i.e. it would be precise) but every measure would be heavier than my actual weight (i.e. it’s inaccurate).
- *Accurate measurements must be precise.* If an answer isn’t reproducible, you’re stuck with the question of which value you should treat as the real one.
- *Digital instruments don’t give more accurate or precise data than analog ones.* An old-style triple beam balance isn’t less awesome because it doesn’t have a digital readout. It’s just older.
- *Always see if measured values pass the idiot test.* If you find that the mass of a textbook is 4300 kilograms, it’s entirely possible that you’ve written down exactly what the balance told you. It’s also 100% certain that the answer is wrong. Remember, it’s easy to make mistakes, and life is easier if you spot them before you finish the experiment.

How to figure out how many significant figures are in a measurement

Before I want to go any further, I want to make it clear that numbers not associated with actual measurements don’t have significant figures. For example, if somebody says “How many significant figures does ‘340’ have?”, there’s no good answer to that. Without knowing that it’s a measured value, you can’t determine which (if any) of the digits are significant, or if it’s simply meant to be a theoretical construct.

In this same vein, you can assume that many conversion factors have an infinite number of significant figures. When you say that there are “100 centimeters in 1 meter”, you don’t need to worry about how many significant figures “100 centimeters” has because one meter is defined as 100 centimeters. It’s not that one meter is *about* 100 centimeters – it is *exactly, to infinite precision, 100 centimeters!*

Measured values, however, aren’t so lucky. Let’s figure them out:

**Rule 1:** *Any digits that are not zeros in a measured value are significant.* For example, the number “229 centimeters” has three significant figures and is assumed to be precise to the nearest centimeter. After all, why would you ever write those numbers unless they meant something?

**Rule 2:** *Any zeros that are stuck between two nonzero digits are significant.* The number “209 centimeters” has three significant figures and is precise to the nearest centimeter. The zero in the

middle isn't anything special, because it just happens that sometimes you have somewhere between 200 and 210 of something.

*Rule 3: Any zero that's in front of all of the nonzero digits is not significant.* For example, if you find that something has a mass of "0.0134 grams", there are only three significant figures, and the value is precise to the nearest 0.0001 gram. If you're wondering whether this rule is arbitrary, you're not being unreasonable. Though the zeros in front of the "134" in this measurement are meaningful, including them as significant figures would screw things up when doing stuff with scientific notation. Roll with it.

*Rule 4: Any zero after all of the nonzero digits is only significant if a decimal is shown.* By this I mean that any zero after all of the nonzero digits is only significant if you *actually see a little point written somewhere in the number*. If you don't actually see a dot drawn in the number, the zeros afterward are not significant. As a result, "210 centimeters" has two significant figures and is precise to the nearest 10 centimeters, while "210. centimeters" has three significant figures and is precise to the nearest centimeter.

*Rule 5: If you're trying to find the number of significant figures for a number written in scientific notation, just look at the part in front of the " $\times 10^4$ " (or whatever the exponent is) to find the sig figs.* If you have a measured value of " $2.10 \times 10^4$  centimeters", you have three significant figures and the number is precise to the nearest  $0.01 \times 10^4$  centimeters (or 10 centimeters).

Some examples using these rules:

- 101 grams has three significant figures and is precise to the nearest gram. The zero between the ones is significant.
- 220 grams has two significant figures and is precise to the nearest ten grams. The zero after the twos is not significant because there is no decimal point explicitly shown.
- 220. grams has three significant figures and is precise to the nearest gram. The decimal point makes that last zero significant.
- 0.0870 grams has three significant figures and is precise to the nearest 0.0001 gram. The zeros before the decimal point are not significant (it doesn't matter if a decimal is shown or not) and the one after the 7 is significant because there is a decimal shown in the number.
- $3.01 \times 10^{-2}$  centimeters has three significant figures (you only look at the "3.01" part, which has three) and is precise to the nearest  $0.01 \times 10^{-2}$  centimeters (or  $1 \times 10^{-4}$  centimeters).

There are practice problems at the end of this tutorial, so if you still don't get it, don't worry about it too much.

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## Doing calculations with significant figures

You have probably already assumed that you'll be doing calculations in chemistry. If you didn't assume that, let me be the first to officially tell you that "you'll be doing calculations in chemistry." I love imparting knowledge.

Unfortunately for those who don't love significant figures, they come into play when doing calculations, too. Let's see why:

Let's assume I want to find the density of a piece of [Styrofoam](#). Using that crummy scale my wife uses to weigh food, I find that the weight is 10 grams. Using the lousy measuring cup in my cabinet, I find that the volume of the [Styrofoam](#) is 90 milliliters. Because the density of an object is equal to its mass over the volume, I'll just [plug these values into my calculator](#) to find that the density of Styrofoam is 0.11111111 grams/mL.

What does this mean? Well, for one thing, it means that Styrofoam isn't very dense, which explains why it floats so well. More importantly, this answer shows that I was able to use really bad equipment to find the density of Styrofoam to the nearest 0.00000001 gram/mL. Given that a balance that can measure to the nearest 0.001 gram (which is nowhere near good enough) costs [\\$2,500](#) and a pipette with the required sensitivity costs [\\$750](#), it would seem I've gotten quite a deal!

So, how do we *really* show the answers to chemistry problems with the correct precision? It depends on the type of calculation you're performing.

### **The rules for calculations with significant figures:**

- Rule 1: When you add or subtract numbers from each other, the answer should be written to the number of decimal places of the least precise number you're starting with. For example, if you're going to add 45 grams (which is precise to the nearest gram) and 29.1 grams (which is precise to the nearest 0.1 gram), the answer will be "74 grams" because the actual number of 74.1 grams rounds to the nearest gram because of the first number. If you were to add 45 grams and 29.6 grams, you'd write the answer as "75 grams" because 74.6 rounded to the nearest whole number is 75.
- Rule 2: When you multiply or divide numbers, the answer should be written with the same number of significant figures as the number with the fewest significant figures. In our example, our answer should be written as "0.1 g/mL" because both 10 grams and 90 mL have one significant figure. Even if we had the best instrument in the world for finding volume and saw that the volume of the Styrofoam was 90.02301113300223448823 mL, the answer would still round to 0.1 g/mL because "10 grams" only has one significant figure.

Some more examples:

- If you have one object that weighs 300 grams and another that weighs 23.2 grams, the weight should be recorded as "300 grams." Though this doesn't seem right, it makes sense when you consider that saying "300 grams" is essentially saying "somewhere between 250 and 349 grams." With that lousy level of precision, the 23.2 gram addition isn't meaningful.
- If I were to find the density of a 91 gram object with a volume of 31.03 mL, the density of the object would be 2.9 g/mL (rounded from 2.936 g/mL because "91 grams" has only two significant figures).
- If you divide an object that weighs 83 grams into four parts, the average mass of each part is 21 grams. Though the number "83 grams" has two significant figures and "4" has one, we only worry about the significant figures in 83 grams because we know we'll have *exactly* four pieces.