Some musings on dilution

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Last modified: August 9, 2013

Dilution by Mass versus Dilution by Volume

If you were to think about the process of diluting a sample from a higher concentration to a lower concentration, most chemistry students (and likely most chemists) would envision doing so volumetrically. We picture using the relationship $C_{conc}V_{conc} = C_{dil}V_{dil}$, to figure out the volume (V_{conc}) of concentrated solution (C_{conc}) we would need to measure to prepare a fixed volume (V_{dil}) of solution at a new concentration (C_{dil}). We could then go into the lab and, using things like pipets and volumetric flasks, prepare the solution.

Many times this volumetric approach is appropriate and quite reasonable, but there are situations where another approach works well. For example, if a material is not compatible with glass pipets and flasks, then using them in the volumetric approach just won't work. In cases like this, we need an alternative approach. Often the easiest approach is to do our dilutions based on <u>mass</u>, instead of volume. Remember, whenever we do a dilution, we are just scaling the concentration of the more concentrated solution down by some dilution factor defined by the ratio of the concentrations of the dilute and concentrated solutions. In the volumetric dilution above, that factor is equal to the ratio of V_{conc} to V_{dil}, as shown below.

$$\text{dilution factor} = \frac{C_{dil}}{C_{conc}} = \frac{V_{conc}}{V_{dil}}$$

Measuring volumes is an easy way to define the dilution factor, but making mass measurements allow us to do that as well. As a matter of fact, we can easily derive a relationship based on dilution by mass: $C_{conc}m_{conc} = C_{dil}m_{dil}$, where we've used masses (m_{conc} and m_{dil}) instead of volumes and concentrations with units of mass (or moles) solute per mass of solution.

Here's an example: Let's say that we have a 1000.0 ppm solution of lead and we need to make 35 ppm solution. In order to prepare this solution, our concentrated solution needs to be diluted by a factor of C_{dil}/C_{conc} or 35/1000. How might we accomplish this both volumetrically and by mass?

How do we attain this dilution factor <u>volumetrically</u>? On a volume basis, the 35/1000 factor means that for every 35 mL of 1000 ppm solution, we would need to dilute the solution to a total volume of 1000 mL (1L!). Practically, how might we accomplish this? One approach would be to plan to prepare 1000 mL of our dilute solution. To do this would require delivering (precisely) 35 mL of our stock solution. The best way to do this would be with a pipet. After scouring the lab, we realize that 35 mL pipets are hard to come by and we need to try another approach. We could use multiple pipets, but each manipulation comes with an increase in uncertainty. Plus, if we only need a few mL of solution, making 1 L may be wasteful. We know that 10 mL pipets are readily available, so why not use one of those instead? If we do that, our 10 mL aliquot would need to be diluted to: 10 mL(1000/35) = 285.71 mL. The best vessel to dilute this solution in would be a volumetric flask, but good luck finding that 285.71 mL volumetric! It looks like a volumetric approach isn't convenient here. Will a mass approach be any better?

To do the <u>dilution by mass</u>, we first measure a mass of our concentrated solution and add enough solvent until we have reached the appropriate dilution factor. Lets say we plan on starting with 5.00 grams of our 1000 ppm solution, what mass of solution must we dilute this to in order to get to 35 ppm? Using the dilution factor, 5.00g(1000ppm/35ppm) = 142.85 g. So, if we go into the lab and place a clean, dry container on a balance, tare the balance, and add

5.00 g of our 1000 ppm solution, we need only add enough water so that the total mass is 142.85 grams in order to prepare a 35 ppm solution! Even if we weighed out 4.95 g of our solution instead of 5.00 g, we could still prepare the diluted solution accurately. We just dilute to 4.95g(1000ppm/35ppm) = 141.43 g instead. As long as we know the initial and final masses, we can readily calculate the final concentration. Mechanically, this is a simpler process than pipetting and filling volumetrics, and leads to the same result!

By now you might probably be asking: Why not dilute by mass always? In principle, we could. But, there are some practical limitations. If precision is critical, we need to take a step back and determine which approach gives us acceptable precision. This is a case-by-case decision. Since for many dilution factors, appropriate pipets and volumetric flasks are available at a lower price than a good balance, so practicality plays a role. Also, we typically try to minimize exposure of electronic equipment to liquids. So, if doing a dilution volumetrically is convenient, we typically do so. But for situations where reagents are limited or where dilution factors preclude the volumetric approach, dilution by mass is the way to go!

Serial Dilutions

Here's another situation. Let's say we want to prepare a 10 ppb solution from our 1000 ppm lead solution above. How might we go about this? Our earlier discussion suggests that we need a dilution factor of 10/1,000,000 = 1/100,000 (remember 1000 ppm = 1,000,000 ppb) to make this happen. Doing this in a single step is pretty challenging and typically results in poor accuracy in the concentration of the diluted solution. If we were going to do this dilution by volume and prepare even 1L (1000 mL) of solution, we would need to begin with: 1000 mL($1/10^5$) = 0.010 mL of our 1000 ppm stock solution. Even with micropipets, measuring 10 μL (0.010 mL) is difficult to do precisely. The dilution by mass approach also has some problems here. If we were to start with 1.00 gram of our stock solution, we would need to dilute it to 100,000 g to obtain our desired concentration. That's about 100 L! Not very practical.

The way around this challenge is to perform the dilution in a series of steps, each one leading to an intermediate concentration until we finally reach the target concentration. This process is known as serial dilution. A serial dilution approach to our problem might go like this:

1. measure 1.00 grams of our 1000 ppm solution and dilute to 100.00 grams to prepare a 10.0 ppm solution. (dilution factor = 1/100)
2. measure 1.00 grams of the 10 ppm solution and dilute to 100.00 grams to make a 100. ppb solution. (dilution factor = 1/100 , overall dilution factor = 1/10,000)
3. measure 1.00 grams of the 100 ppb solution and dilute to 10.00 grams to prepare a 10.0 ppb solution. (dilution factor = 1/10, overall dilution factor = 1/100,000)

We could develop a volumetric approach as well, but the process is really the same. Ultimately, we end up with the same dilution factor, but in a more practical manner. In order to maximize precision and minimize error, we try to keep the number of intermediate concentrations to the minimum, within the constraints of what is practical.