Sections 2.3 (Atoms-First) and 8.3 (Chemistry-First) Density and Density Calculations

An Introduction to Chemistry

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Density

- ***Mass density*** is mass divided by volume. It is usually just called density.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

- Density usually has the units of g/mL for solids and liquids and g/L for gases.

Uses for Density

- It is possible to identify an unknown substance by comparing its density at a particular temperature to the densities of known substances at that temperature. (See Table 2.2 or 8.2 for a list of densities.)
- Density can be used as a unit analysis conversion factor that converts mass to volume or volume to mass.

Example 2.7 and 8.7: What is the volume of 25.00 kg water at 20 °C?

- Don't forget to take small steps.
  - Set the unit you want to get equal to the value you are given.

$$? \text{ L } H_2O = 25.00 \text{ kg } H_2O$$

  - Set up the skeleton of the first conversion factor.

$$? \text{ L } H_2O = 25.00 \, \cancel{\text{kg}} \, H_2O \left(\frac{\quad}{\cancel{\text{kg}}} \right)$$

- Ask yourself whether you know a conversion factor that will take you directly from the unit that you have to the unit you want. (In this case, let's assume that the answer is no.)

Example 2.8 and 8.8: What is the volume of 25.00 kg water at 20 °C?

- If you can't see how to make your conversion in one step, ask yourself what type of unit you're converting from and what type of unit are you converting to.
- In this case, we are converting from mass into volume, which is our tip-off that we need the density, which you are likely to get from a table of densities.
- The density of water at 20 °C is 0.9982 g/mL.

Example 2.8 and 8.8: What is the volume of 25.00 kg water at 20 °C?

- Like any other conversion factor, density can be used in two forms. The first form below can be used to convert from volume in mL to mass in g, and the second form can be used to convert mass in g to volume in mL. We will use the second form.

$$\frac{0.9982 \text{ g } H_2O}{1 \text{ mL}} \quad \text{or} \quad \frac{1 \text{ mL}}{0.9982 \text{ g } H_2O}$$

Example 2.8 and 8.8: What is the volume of 25.00 kg water at 20 °C?

- Before we can convert from g to mL, we need to convert from kg to g.
- After converting to mL with the density, we convert from mL to L.
- Our plan is to use three conversion factors to make the following conversions.

  kg → g → mL → L

$$? \text{ L H}_2\text{O} = 25.00 \text{ kg H}_2\text{O} \left(\frac{\text{g}}{\text{kg}}\right)\left(\frac{1 \text{ mL H}_2\text{O}}{0.9982 \text{ g H}_2\text{O}}\right)\left(\frac{\text{L}}{\text{mL}}\right)$$

Example 2.8 and 8.8: What is the volume of 25.00 kg water at 20 °C?

- Let's go back to the beginning of our setup.

$$? \text{ L H}_2\text{O} = 25.00 \, \cancel{\text{kg}} \, \text{H}_2\text{O} \left(\frac{\quad}{\cancel{\text{kg}}} \right)$$

- We get the conversion factor that will take us from kg to g from the definition of kilo, which is 10^3.

$$? \text{ L H}_2\text{O} = 25.00 \, \cancel{\text{kg}} \, \text{H}_2\text{O} \left(\frac{10^3 \text{ g}}{1 \, \cancel{\text{kg}}} \right)$$

- Next, we set up the skeleton of the next conversion factor.

$$? \text{ L H}_2\text{O} = 25.00 \, \cancel{\text{kg}} \, \cancel{\text{H}_2\text{O}} \left(\frac{10^3 \, \cancel{\text{g}}}{1 \, \cancel{\text{kg}}} \right) \left(\frac{\quad}{\cancel{\text{g}} \, \cancel{\text{H}_2\text{O}}} \right)$$

Example 2.8 and 8.8: What is the volume of 25.00 kg water at 20 °C?

- Our core conversion is to convert g to mL using the density.

$$? \text{ L } H_2O = 25.00 \cancel{\text{kg}} \cancel{H_2O} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \text{ mL } H_2O}{0.9982 \cancel{\text{g}} \cancel{H_2O}}\right)$$

- We now set up the skeleton for the next conversion.

$$? \text{ L } H_2O = 25.00 \cancel{\text{kg}} \cancel{H_2O} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mL}} H_2O}{0.9982 \cancel{\text{g}} \cancel{H_2O}}\right)\left(\frac{\quad}{\cancel{\text{mL}}}\right)$$

- We get the conversion factor that will take us from mL to L from the definition of milli, which is 10^{-3}.

$$? \text{ L } H_2O = 25.00 \cancel{\text{kg}} \cancel{H_2O} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mL}} H_2O}{0.9982 \cancel{\text{g}} \cancel{H_2O}}\right)\left(\frac{1 \text{ L}}{10^3 \cancel{\text{mL}}}\right)$$

Example 2.8 and 8.8: What is the volume of 25.00 kg water at 20 °C?

$$? \text{ L } H_2O = 25.00 \cancel{\text{kg } H_2O} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}} \right) \left(\frac{1 \cancel{\text{mL}} \text{ } H_2O}{0.9982 \cancel{\text{g } H_2O}} \right) \left(\frac{1 \text{ L}}{10^3 \cancel{\text{mL}}} \right)$$

$$= 25.05 \text{ L } H_2O$$

- Check to be sure that you have used conversion factors for which you have high confidence that they are correct.
- Check to be sure that your units cancel.
- Use the calculator to complete the calculation (25.0450811).
- Report your answer to the correct significant figures.
- Be sure to add the correct unit to your answer.

Practice

- To get some practice, work Exercise 2.7 in the atoms-first version of my text or Exercise 8.7 of the chemistry-first version and Problems 64-67.

Example 2.9 and 8.9: An empty 2-L graduated cylinder is found to have a mass of 1124.2 g. Liquid methanol, CH_3OH, is added to the cylinder, and its volume measured as 1.20 L. The total mass of the methanol and the cylinder is 2073.9 g, and the temperature of the methanol is 20 °C. What is the density of methanol at this temperature?

- One of the most useful initial strategies for working word problems is to write down the values that you are given, separating them from the words.
- Sometimes you can just write down the number and unit. For example,
  - 1124.2 g
  - 1.20 L
  - 2073.9 g
- If the values refer to more than one thing, it's best to identify what your values refer to. For our example,
  - 1124.2 g grad cyl
  - 1.20 L CH_3OH
  - 2073.9 g grad cyl/CH_3OH

Example 2.9 and 8.9: An empty 2-L graduated cylinder is found to have a mass of 1124.2 g. Liquid methanol, CH_3OH, is added to the cylinder, and its volume measured as 1.20 L. The total mass of the methanol and the cylinder is 2073.9 g, and the temperature of the methanol is 20 °C. What is the density of methanol at this temperature?

- Unless you are told otherwise, describe the density of solids and liquids with units of g/mL. When starting your unit analysis setup, be sure that it's clear that g is on the top and mL is on the bottom.

$$\frac{?\ \text{g}}{\text{mL}} = \qquad \text{not} \quad ?\ \text{g/mL} =$$

- Because we want our answer to contain a ratio of two units, we start the right side of our setup with a ratio of two units. Our next little step is to put a line on the right side of the equals sign.

$$\frac{?\ \text{g}}{\text{mL}} = \frac{\qquad\qquad}{\qquad\qquad}$$

Example 2.9 and 8.9: An empty 2-L graduated cylinder is found to have a mass of 1124.2 g. Liquid methanol, CH_3OH, is added to the cylinder, and its volume measured as 1.20 L. The total mass of the methanol and the cylinder is 2073.9 g, and the temperature of the methanol is 20 °C. What is the density of methanol at this temperature?

- Because we want mass on the top when we are done and volume on the bottom, we put our mass unit on the top and our volume unit on the bottom.
- The mass of the methanol is found by subtracting the mass of the cylinder from the total mass of the cylinder and the methanol.

$$\frac{?\ \text{g}}{\text{mL}} = \frac{(2073.9 - 1124.2)\ \text{g}}{1.20\ \text{L}}$$

Example 2.9 and 8.9: An empty 2-L graduated cylinder is found to have a mass of 1124.2 g. Liquid methanol, CH_3OH, is added to the cylinder, and its volume measured as 1.20 L. The total mass of the methanol and the cylinder is 2073.9 g, and the temperature of the methanol is 20 °C. What is the density of methanol at this temperature?

- We now have units of g/L instead of g/mL, so we have to convert L to mL.
- Because we want to cancel L, and because it is on the bottom of the first ratio, the skeleton of the next conversion factor has the L on top.

$$\frac{?\,\text{g}}{\text{mL}} = \frac{(2073.9 - 1124.2)\,\text{g}}{1.20\,\cancel{\text{L}}}\left(\frac{\cancel{\text{L}}}{\phantom{10^3\,\text{mL}}}\right)$$

- The m in mL represents milli, which is 10^{-3}, so there must be 10^3 mL per L.

$$\frac{?\,\text{g}}{\text{mL}} = \frac{(2073.9 - 1124.2)\,\text{g}}{1.20\,\cancel{\text{L}}}\left(\frac{1\,\cancel{\text{L}}}{10^3\,\text{mL}}\right)$$

Example 2.9 and 8.9: An empty 2-L graduated cylinder is found to have a mass of 1124.2 g. Liquid methanol, CH_3OH, is added to the cylinder, and its volume measured as 1.20 L. The total mass of the methanol and the cylinder is 2073.9 g, and the temperature of the methanol is 20 °C. What is the density of methanol at this temperature?

- Because the order of operations calls for multiplication and division to be done before addition and subtraction, it's a good habit to always put the numbers for additions and subtractions in parentheses when doing the calculations on your computer or calculator. One way to do this calculation is below. (Different calculators and computers call for inputting scientific notation for numbers in different ways, but in this case, we can use 1000 for 10^3.)

$$(2073.9 - 1124.2) \div 1.2 \div 1000 =$$

- The computer shows the answer as 0.791416666666666666666666666667, but we need to round this to the correct significant figures.

Example 2.9 and 8.9: An empty 2-L graduated cylinder is found to have a mass of 1124.2 g. Liquid methanol, CH_3OH, is added to the cylinder, and its volume measured as 1.20 L. The total mass of the methanol and the cylinder is 2073.9 g, and the temperature of the methanol is 20 °C. What is the density of methanol at this temperature?

- Because 2073.9 and 1124.2 are both reported to the tenth decimal position, we round the subtraction to the first decimal position (949.7).
- The 1.20 has three significant figures and 10^3 is exact, so we round our answer (0.791416666666666666666666666667) to three significant figures.

$$\frac{?\ \text{g}}{\text{mL}} = \frac{(2073.9 - 1124.2)\ \text{g}}{1.20\ \cancel{\text{L}}}\left(\frac{1\ \cancel{\text{L}}}{10^3\ \text{mL}}\right) = \mathbf{0.791\ g/mL}$$

Practice

- To get some practice, work Exercise 2.8 in the atoms-first version of my text or Exercise 8.8 in the chemistry-first version and Problems 62 and 63.