Density

A. Introduction

Density is the ratio of mass to volume; d = m/V. Because d is such a ratio, it is an intensive property. That is, d is a property of the material, but does not depend on how much you have.

> [d also depends on conditions, especially temperature and pressure. Effects of these variables are very large for gases, but modest for solids and liquids. We will ignore them here.]
>
> The Greek letter ρ (rho) is also used for density.

The density equation contains three terms (d, m, V). In general, in density problems you know two of these and want to calculate the third.

Most density problems can be solved by careful attention to the units, even if you do not precisely remember the above equation. In fact, this worksheet assumes that you generally understand the use of dimensional analysis as a problem solving tool; see the Dimensional Analysis worksheet if you want some help with that topic.

B. Calculate d

To calculate d, you need to measure the mass and volume of some amount of the material.

Example

You have a piece of copper. Its volume is 9.27 mL and its mass is 82.9 g. Calculate the density of copper.

$$d = \frac{m}{V} = \frac{82.9\ g}{9.27\ mL} = 8.94\ g/mL$$

Note the units of density, g/mL. These units reflect the equation, mass/volume.

Problems

1. You measure out 5.00 mL of concentrated nitric acid, HNO_3. It weighs 7.10 g. What is the density of concentrated nitric acid? [Note. This refers to common lab "concentrated nitric acid", which is about 70% (w/w) HNO_3.]
2. A 34.6 g bar of aluminum occupies 12.8 mL. Calculate the density of aluminum.

C. Calculate m

You can calculate the mass of something from its volume, if you know the density. That is, given d and V, you can calculate m. If you do algebra on the density equation, you see that m = d*V. You can use this equation, and use the units as a check. Or you can just follow the units. In effect, such a problem asks you to convert V to m (mL to g).

Example

The density of ethanol (ethyl alcohol) is 0.789 g/mL. Calculate the mass of 10.0 mL.

$$m = 10.0\ \cancel{mL} \times \frac{0.789\ g}{\cancel{mL}} = 7.89\ g$$

Emphasize: Check the units, even if you start by using the equation. The units will protect you from some silly mistakes.

Problems of this type may be particularly common for liquids. It's often convenient to measure a liquid by volume, but you may need to know the mass of the sample, perhaps so you can convert it to moles.

Problems

3. What is the mass of 150 mL ethanol? (d is in the Example, above).
4. Continuing… How many moles is this? (Ethanol is C_2H_5OH.)
5. Calculate the mass of 100 mL of concentrated nitric acid (density = 1.42 g/mL).
6. Continuing… What is the actual mass of HNO_3 in that 100 mL? (Remember, the "concentrated" acid is 70% HNO_3 by weight.)
7. Continuing… How many moles is that?

D. Calculate V

From the density equation, V = m/d. Again, you can use this and check yourself with the units. Or you can use the units alone to guide the problem. Problems of this type involve converting m to V (g to mL).

Example

What is the volume of an 18.2 g piece of aluminum (d = 2.70 g/mL)?

$$V = 18.2\ \cancel{g} \times \frac{mL}{2.70\ \cancel{g}} = 6.74\ mL$$

Note that we wrote the density upside down here, in order to cancel the g and get the answer in mL. This is equivalent to dividing by d, as the equation indicated.

Problems

8. What is the volume of a 23.9 g piece of gold, d = 19.3 g/mL?
9. Given 134 g of concentrated nitric acid (d = 1.42 g/mL), what is the volume?

E. Misc problems

These problems are similar to the problems in the three sections above.

Problems. (Most d values are in previous problems.)

10. Given 12.8 mL of concentrated nitric acid, what is its mass?
11. What is the volume of 4.20 g of ethanol?
12. You have 173 g of gold. What is its volume?
13. The weight of 9.28 mL of ethanol is 7.31 g. Calculate the density of ethanol, based on these data.
14. An aluminum bar has mass 242 g. What is its volume?
15. An aluminum bar occupies 5.32 mL. How much does it weigh?

F. More complexity?

There are only three basic kinds of density problems. These are covered in Sect B-D. After all, there are only three terms in the density equation.

The main possible source of additional complexity would be in the units. For example, d may be given in g/mL but you want m in kg (or even pounds). Or you may have measured the volume in liters (or even ounces), and want d in g/mL.

To do problems such as these, remember that density is fundamentally mass/volume. You can change the mass units from one to another, and you can change the volume units from one to another; but these changes do not change the basic form of the solution. Show each step as a simple dimensional analysis conversion, and the units will guide you.

Example

Calculate the mass of 2.40 L of ethanol, d = 0.789 g/mL. That is, convert 2.40 L to g.

$$m = 2.40\ \cancel{L} \times \frac{0.789\ g}{\cancel{mL}} \times \frac{1000\ \cancel{mL}}{\cancel{L}} = 1890\ g\ (\text{to 3 SF})$$

Of course, you might do this other ways. For example, you might immediately recognize that 2.40 L = 2400 mL, and start the problem with 2400 mL. What you have done in that case is to do one conversion step in your head. L still gets converted to mL, either in your head or on paper. The example solution shown above shows all work. If at all in doubt, this is the safe way to do the problem.

Problems. I encourage you to show all steps explicitly. (Most d values are in previous problems.)

16. Calculate the mass of 5.00 L of concentrated nitric acid.
17. What is the volume of 2.00 mg of gold?
18. What is the mass of 2.0 mL of air, d = 1.2 g/L?
19. What is the volume of an aluminum bar which weighs 1.88 kg?
20. Calculate the volume of 25.0 mmol of ethanol.

G. Answers

Sect B

1. $d = \frac{7.10\ g}{5.00\ mL} = 1.42\ g/mL$

2. 2.70 g/mL

Sect C

3. 118 g
4. 2.57 mol (Note that the simple conversion from mass to moles works only if the substance is pure, that is, if 100% of the weight is ethanol. If it isn't, you need to do a further calculation, as the next group of problems illustrates.)
5. 142 g
6. 99.4 g
7. 1.58 mol [This is the number of moles of HNO_3 in 100 mL of "concentrated" -- 70% (w/w) -- nitric acid.]

Sect D

8. 1.24 mL
9. 94.4 mL

Sect E

10. 18.2 g
11. 5.32 mL
12. 8.96 mL

13. 0.788 g/mL
14. 89.6 mL
15. 14.4 g

Sect F

16. 7100 g = 7.10 kg (Compare to #1)
17. 1.04×10^{-4} mL = 0.104 μL
18. 2.4×10^{-3} g = 2.4 mg
19. 696 mL
20. 1.46 mL

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