Unit Conversion and Dimensional Analysis

Frequently in Chemistry you will be provided with data describing a particular quantity in a certain unit of measurement, and you will be required to convert it to a different unit which measures the same quantity. This process is frequently described as Unit Conversion. As an example, you may be given a measurement of length in centimeters which must be converted to meters. This worksheet includes the rules and some guidelines to help you with converting, density problems, stoichiometry problems, and concentration problems. This worksheet is not intended to help you with reading comprehension of word problems regarding these types of questions, just the mathematical application.

Rules

1.) Identify the **given** measurement.
2.) Identify the **unit** that the measurement must be converted to.
3.) Use **conversion factors** (relationship between two units) that link your given unit to your final unit.
4.) Perform the mathematical calculations.
5.) Do **not** forget to apply significant figures to your final answer.

Guidelines

1.) When converting a single unit, such as converting from centimeters to meters, the given should also be a single unit as well. It can become more difficult by starting with the conversion factor: (100 cm / 1 m). Even if you know a dozen = 12, the relationship cannot be applied if you do not know how many dozen you care about.
2.) When only a single unit given, it should be written over 1. For example, 56.93 cm should be written as 56.93 cm / 1. Units lacking a number are assumed to be 1. If we were given 1.193 g / ml, we would write this as 1.193 g / 1 ml .
3.) Any relationship between two units can potentially be utilized as a conversion factor: density relates mass and volume while molar mass relates moles and mass. Express these conversion factors as a fraction in the dimensional analysis.
4.) A conversion factor can be written in **two** different ways. For example, converting centimeters and meters, we can use the conversion factor (100 cm / 1 m) or (1 m / 100 cm). The unit you want to remove from the problem should be placed **opposite** of the original. So, to convert from cm to m, cm is your given unit, and the cm should be in the bottom to denominator out cm from the problem.

5.) The math should be the **last** thing you do. By first cancelling units, so that your final unit is the only one, you may easily check that the conversion has been set up correctly. The math calculation will follow this.
6.) Standardized conversion factors are **never** used to calculate significant figures. Multiplying by the conversion factor (100 cm / 1 m) will not affect your significant digits.

Example

Problem: Convert: 56.93 cm to m

Solution:

1.) The given measurement is 56.93 cm.
2.) The measurement must be converted to meters.
3.) The conversion factor(s) we need to use either has to directly relate cm and m, or chain to cancel all units except m. Luckily, we know a direct one: 100 cm is equal to 1 m. cm should be in the denominator to cancel with the original cm.
4.) $$\frac{56.93\ \cancel{\text{cm}}}{1} \times \frac{\text{m}}{100\ \cancel{\text{cm}}} = \frac{56.93\ \text{m}}{100} = .5693\ \text{m (significant figures applied)}$$

Practice Problems

Note: Unless you are **confident** in your ability to determine **direct** conversion factors, such as cm to km, it is highly recommended to convert to the **standard** unit. This allows one to relate cm to m, and then m to km.

1.	87.68 kg to g	11.	5055 mm to m	21.	2133 mL to L	31.	81.77 mg to kg
2.	543.7 dm to m	12.	222.9 dg to g	22.	80.66 L to dL	32.	4.116 km to mm
3.	2417 m to mm	13.	794.2 km to m	23.	874.2 m to dm	33.	6.908 dL to kL
4.	8506 cg to g	14.	4.807 kL to L	24.	557.2 g to cg	34.	94.93 kg to dg
5.	3841 cL to L	15.	38.92 mg to g	25.	87.66 m to km	35.	2.525 mg to kg
6.	218.1 km to m	16.	89.55 m to cm	26.	20.01 L to dL	36.	178.2 kL to cL
7.	772.8 g to kg	17.	3.889 mL to L	27.	7022 dg to g	37.	0.0005359 kg to mg
8.	15.47 kL to L	18.	4.102 g to mg	28.	9.319 L to cL	38.	0.04582 kL to mL
9.	67.42 dL to L	19.	6841 mL to L	29.	5.604 g to dg	39.	987.6 cm to km
10.	.85 m to mm	20.	39.24 cm to m	30.	19.5 g to mg	40.	1511 km to dm

Practice Problems: Answers

1.	87680 g	11.	5.055 m	21.	2.133 L	31.	8.177×10^{-5} kg
2.	5437. m	12.	22.29 g	22.	806.6 dL	32.	4.116×10^{6} mm
3.	2417000 mm	13.	794200 m	23.	8742. dm	33.	6.908×10^{-4} kL
4.	85.06 g	14.	4807 L	24.	55720 cg	34.	9.493×10^{5} dg
5.	38.41 L	15.	0.03892 g	25.	0.08766 km	35.	2.525×10^{-6} kg
6.	218100 m	16.	8955 cm	26.	200.1 dL	36.	1.782×10^{7} cL
7.	0.7728 kg	17.	0.003889 L	27.	702.2 g	37.	5.359×10^{2} mg
8.	15470 L	18.	4102 mg	28.	931.9 cL	38.	4.582×10^{4} mL
9.	6.742 L	19.	6.841 L	29.	56.04 dg	39.	9.876×10^{-3} km
10.	850 mm	20.	0.3924 m	30.	0.0195 mg	40.	1.511×10^{7} dm

Density Example

Problem: Calculate the mass in grams of 14.79 ml of a substance. Its density is 1.193 g/ml.

Solution:

1.) The given measurement is 14.79 ml.
2.) It must be converted to grams.
3.) The conversion factor has to relate mass and volume. Luckily, density is supplied, and its units are g/ml, a mass and volume unit. The number 1.193 belongs to the gram unit, and is placed on the top so that the ml units can cancel out.
4.) $\frac{14.79\ \cancel{ml}}{1} \times \frac{1.193\ g}{\cancel{ml}} = \frac{17.64\ g}{1} =$ 17.64 g (significant figures applied)

Density Practice Problems

1.	17. g to mL, density = 3.291 g / mL	21.	854.8 cg to cL, density = 20.15 g / mL
2.	96.92 g to mL, density = 0.243 g / mL	22.	5214.000 L to kg, 4.818 g / mL
3.	62.59 mL to g, density = .5074 g / mL	23.	96.02 dL to mg, density = 7.27 g / mL
4.	4409. mL to g, density = .8449 g / mL	24.	.796 kL to dg, density = 0.9237 g / mL
5.	4155. g to mL, density = 1.291 g / mL	25.	80.03 kg to kL, density = 26.73 g / mL
6.	3.38 mL to g, density = 1.411 g / mL	26.	4.946 dL to mg, density = 7.4352 g / mL
7.	92.86 g to mL, density = 10.71 g / mL	27.	519.0 cL to dg, density = 0.8437 g / mL
8.	921.5 g to mL, density = 38.35 g / mL	28.	8830.0 mg to L, density = 4.848 g / mL
9.	53.08 mL to g, density = 60.83 g / mL	29.	76.09 dL to cg, density = 1.185 g / mL
10.	7.85 mL to g, density = 2.643 g / mL	30.	855.5 kL to kg, density = 0.695 g / mL
11.	3.23 kg to mL, density = 0.4059 g / mL	31.	980.3 dg to kL, density = 1.679 kg / L
12.	6.247 g to kL, density = 1.066 g / mL	32.	6.433 L to mg, density = 7.685 cg / dL
13.	3858. mg to mL, density = 1.492 g / mL	33.	701.4 dg to mL, density = 4.494 mg / cL
14.	5.567 mL to dg, density = 0.7086 g / mL	34.	7612.00 L to kg, density = 39.3 dg / dL
15.	9632.00 g to cL, density = 1.8020 g / mL	35.	5.423 mg to cL, density = 0.8178 Kg / dL
16.	607.3 dL to g, density = 1.2 g / mL	36.	79.72 cg to dL, density = 0.9770 dg / L
17.	3.019 cg to mL, density = 1.306 g / mL	37.	3298. cL to mg, density = 1.613 cg / mL
18.	7143.0 L to g, density = 0.438 g / mL	38.	95.57 kL to g, density = 3.445 cg / cL
19.	329.1 mg to mL, density = 2.522 g / mL	39.	8738 kg to mL, density = 0.5409 cg / kL
20.	63.47 g to L, density = 41.939 g / mL	40.	843.10 mL to kg, density = 0.7166 g / dL

Density Practice Problems: Answers

1.	5.2 mL	11.	7960 mL	21.	0.04242 cL	31.	0.00005839 kL
2.	399. mL	12.	5.860×10^{-6} kL	22.	25120 kg	32.	4944. mg
3.	31.76 g	13.	2.586 mL	23.	698000 mg	33.	156100 mL
4.	3725. g	14.	0.3945 dg	24.	7350000 dg	34.	300. kg
5.	3218. mL	15.	534.52 cL	25.	0.002994 kL	35.	0.00006631 cL
6.	4.77 g	16.	73000 g	26.	3677000 mg	36.	81.60 dL
7.	8.670 mL	17.	0.02312 mL	27.	43790 dg	37.	5.320 x 10^5 mg
8.	24.03 mL	18.	3129000 g	28.	0.001821 L	38.	329200 g
9.	3229. g	19.	0.1305 mL	29.	901700 cg	39.	1.615 x 10^15 mL
10.	20.7 g	20.	0.001513 L	30.	595000 kg	40.	0.006042 kg

Molecule / Mole Stoichiometry Example

Problem: Based on the balanced chemical equation: $C + O_2 \rightarrow CO_2$, how many molecules of carbon dioxide could be produced from 20 atoms of carbon in the presence of excess oxygen?

Solution:

1.) The given measurement is the 20 carbon atoms.
2.) This must be converted to molecules of carbon dioxide.
3.) The conversion factor has to relate carbon atoms and carbon dioxide molecules. Luckily, one can use a balanced chemical equation, such as the one above, to determine a conversion factor between the two different substances. The ratio is 1 C : 1 CO_2, and the carbon be in the denominator of the fraction to cancel the given carbon unit.
4.) $$\frac{20\ \cancel{C}}{1} \times \frac{1\ CO_2}{1\ \cancel{C}} = \frac{20\ CO_2}{1} = 20\ CO_2$$ molecules (significant figures applied)

Molecule / Mole Stoichiometry Practice Problems

Note: Be specific when writing conversion factors representing chemicals. You should include not only the unit of measure, but also the identity of the chemical itself.

Note: When taking two reactants to see how much product they can produce, it is necessary to check for the limiting reagent, the one you have less of after converting to moles and accounting for the ratio in which it reacts.

$$2\ N_2O_5 \rightarrow 2\ N_2 + 5\ O_2$$

1.	How many molecules of nitrogen gas are produced from a reaction yielding 225 molecules of oxygen gas?
2.	How many molecules of dinitrogen pentoxide are required to produce 164 molecules of nitrogen gas for your gas molecule collection?
3.	When 40 molecules of oxygen gas are produced, how many molecules of nitrogen gas byproduct are produced?
4.	How many molecules of dinitrogen pentoxide are consumed in the formation of 1,870 molecules of oxygen gas?
5.	How many molecules of nitrogen gas and oxygen gas are produced in the decomposition of 643 molecules of dinitrogen pentoxide?

$$C_5H_{12} + 8\ O_2 \rightarrow 5\ CO_2 + 6\ H_2O$$

6.	From a reaction that produced 2,238 molecules of water vapor, how many carbon dioxide molecules would you expect to be formed?
7.	Your dragon sneezes and ignites 187 molecules of pentane, how many molecules of water vapor are produced?
8.	From the production of 170 molecules of carbon dioxide, how much oxygen gas was required for this reaction?
9.	How much oxygen is required for the combustion of 6,914 molecules of pentane?
10.	How many molecules of carbon dioxide and water vapor were produced in question 9?

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

11.	From the reaction of 147.2 moles of octane with all needed oxygen, how many moles water vapor are produced as a result?
12.	Your experiment yields 4.283 moles of carbon dioxide, how many moles water vapor are produced as a byproduct?
13.	With excess octane, 42.05 moles of oxygen gas reacts, generating how many moles of carbon dioxide?
14.	You want to produce 97.48 moles of carbon dioxide as a gift to your chemistry professor, how many moles of octane should you start with?
15.	With 200. moles of octane and 164.71 moles of oxygen gas in your reaction mixture, how many moles of carbon dioxide and water vapor can be produced?

$$2\ Fe(NO_3)_3 \quad + \quad 3\ MgO \quad \rightarrow \quad Fe_2O_3 \quad + \quad 3\ Mg(NO_3)_2$$

16.	In order to obtain 132.843 moles of magnesium nitrate, how many moles of magnesium oxide must be reacted?
17.	After a reaction runs to completion, you obtain 27.13 moles of magnesium nitrate. How many moles of iron(III)nitrate were consumed?
18.	Determine how many moles iron(III)nitrate are required to synthesize 421.0 moles of iron(III)oxide.
19.	You react 7.23 moles of iron(III)nitrate and 11.48 moles of magnesium oxide in the magnesium nitrate lab you set up in your bathroom, producing how many moles of iron(III)oxide waste?
20.	How many moles of magnesium nitrate product was formed in problem 19?

$$4\ (NH_4)_3N \quad + \quad 3\ Cr(CrO_4)_2 \quad \rightarrow \quad 6\ (NH_4)_2CrO_4 \quad + \quad Cr_3N_4$$

21.	What mass of ammonium chromate is produced in the complete reaction of 8.1934 moles of ammonium nitrate?
22.	94.18 grams of chromium(IV)nitrate are collected after your experiment. How many moles of chromium(IV)chromate reacted to produce this mass?
23.	1.0 gram of chromium(IV)chromate is reacted with excess ammonium nitrate to produce how many moles of ammonium chromate?
24.	In an effort to resurrect your first dead pet, the Necronomicon requires 666 moles of chromium(IV)nitrate. How many grams of each reactant are required for Fluffy to be reborn?
25.	Determine the moles of ammonium chromate generated in the reaction of 1407 grams of ammonium nitrate and 153.8 grams of chromium(IV)chromate.

$$Cu_3(PO_4)_2 \quad + \quad 3\ Na_2SO_4 \quad \rightarrow \quad 2\ Na_3PO_4 \quad + \quad 3\ CuSO_4$$

26.	What mass of sodium phosphate and copper(II)sulfate is produced from the reaction of 47.002 moles of sodium sulfate?
27.	You wish to produce 131.9 grams of copper(II)sulfate. To do so, you require how many moles of copper(II)phosphate?
28.	When 80 moles of sodium sulfate are reacted, what mass of copper(II) sulfate is produced?
29.	The lab procedure requires 45.61 grams of copper(II)phosphate and 94.65 grams of sodium sulfate. How many moles of sodium phosphate are produced?
30.	A mole would like to make a statue of his wife out of exactly 1.00 mole of sodium phosphate. He knows I'm good for the sodium sulfate but needs you to provide what mass of copper(II)phosphate for the reaction?

$$AlCl_3 + 3\,H_2O \rightarrow Al(OH)_3 + 3\,HCl$$

31.	You accidently add an unknown mass of aluminum chloride into your reaction mixture containing 47.0 grams of water. On completion, your reaction mixture yields 47.00 grams of aluminum hydroxide. Determine the mass of aluminum chloride.
32.	You trap 6.99 grams of hydrogen chloride from a reaction. How much aluminum chloride was required to produce this quantity?
33.	In a misguided attempt to completely remove any water from your favorite cup, you add 40.00 grams of aluminum chloride. On removal, 14.328 grams of aluminum hydroxide are recovered. How much hydrogen chloride is produced in what is no longer your morning coffee mug?
34.	You isolate 9.35 grams of aluminum hydroxide and 9.35 grams of hydrogen chloride from a reaction mixture. What is the minimum mass of each reactant necessary to produce this combination?
35.	From the remaining product in problem 34, how much water was required to produce its mass?

$$4\,HOCl + C \rightarrow 2\,H_2O + CO_2 + 2\,Cl_2$$

36.	On running this experiment in the lab, your apparatus for collecting water and carbon dioxide malfunctions. Knowing that you started with only 2.965 grams of carbon and 12.09 grams of hypochlorous acid, what should have been your mass yield for each?
37.	You are trying to find the carbon content in a 56.32 gram sample of coal, supposedly 75.41% carbon by weight. What mass of chlorine gas should be released on reaction?
38.	The chlorine gas and carbon dioxide gas from the previous problem would be a mixture. What mass of carbon dioxide would be present?
39.	You foolishly believe if you run out of pencil graphite during your chemistry final that you would be excused from taking it. What mass of hypochlorous acid would be required to consume the 0.04 grams in your writing instrument?
40.	What total mass of products was formed through the reaction of 272.17 grams hypochlorous acid and 14.41 grams of carbon?

<u>Molecule / Mole Stoichiometry Practice Problems: Solutions</u>

1.	90 N_2 molecules	21.	1868.1 g $(NH_4)_2CrO_4$
2.	164 N_2O_5 molecules	22.	1.333 moles $Cr(CrO_4)_2$
3.	16 N_2 molecules	23.	0.021 moles $(NH_4)_2CrO_4$
4.	374 N_2O_5 molecules	24.	181000 grams $(NH_4)_3N$ and 567000 grams $Cr(CrO_4)_2$
5.	1286 N_2 and 3215 O_2 molecules	25.	1.083 moles $(NH_4)_2CrO_4$
6.	1865 CO_2 molecules	26.	5137.0 grams Na_3PO_4 and 7502.0 grams $CuSO_4$
7.	1122 H_2O molecules	27.	104.8 moles $Cu_3(PO_4)_2$
8.	272 O_2 molecules	28.	4000 grams $CuSO_4$
9.	55312 O_2 molecules	29.	39.29 moles Na_3PO_4
10.	34570 CO_2 and 41484 H_2O molecules	30.	190. grams $Cu_3(PO4)_2$
11.	1325. moles H_2O	31.	78.55 grams $AlCl_3$
12.	4.818 moles H_2O	32.	8.33 grams HCl
13.	26.91 moles CO_2	33.	20.092 grams HCl
14.	12.19 moles C_8H_{18}	34.	4.62 grams H_2O and 11.1 grams $AlCl_3$
15.	105.41 moles CO_2 and 118.59 moles H_2O	35.	1.86 grams H_2O
16.	132.843 moles MgO	36.	0.6921 grams CO_2 and 2.075 grams H_2O
17.	18.09 moles $Fe(NO_3)_3$	37.	501.4 grams Cl_2
18.	842.0 moles $Fe(NO_3)_3$	38.	169..7 grams CO_2
19.	3.62 moles Fe_2O_3	39.	0.7 grams HOCl
20.	10.9 moles $Mg(NO_3)_2$	40.	271.0 grams of products