CHM 0100 Preview of General Chemistry

Chapter 1: Math for science

Using Math: Many students promptly forget their math classes, as soon as they finish them. That's not OK in science. You may have thought during your math class, "Who uses algebra in real life?" Scientists do! In Science, you are literally required to remember and use all of the math that you have ever taken, from kindergarten on up. Some science professors are willing to review math, but most are not.

Using a SCIENTIFIC CALCULATOR: You are required to buy and learn how to use a scientific calculator. No one does long calculations by hand anymore in science/ engineering, unless they're showing off. Some scientists, especially Physicists, do show off, but we don't need you to show off. You do not need a $150 calculator, unless you intend to become a professional scientist or engineer. The Texas Instruments TI-30Xa is less than $20; the TI-36X is less than $25. Your smartphone has a built-in calculator app that you may use in an emergency, but you may not use it for tests.

ABBREVIATIONS: Scientists are very lazy. They refuse to write anything out completely; they abbreviate everything. Every letter of the alphabet, upper and lower case, stands for something. You must continually practice using them - for measurements, for units or for technical terms - so that they become second nature. Some students find flash cards helpful to remember factoids like abbreviations.

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the metric system

Scientists measure EVERYTHING, and they always use the METRIC SYSTEM (the Système International). Unfortunately, the United States is almost literally the last country on Earth that still uses British (or Imperial) units for ordinary purposes. (Even the British don't use British units anymore.)

Students must be comfortable with the metric system. This means being familiar with real things in metric units, such as - a paper clip weighs about 1 gram, a high ceiling is about 3 meters, a 40°C day is extremely hot and uncomfortable, a 50 square meter apartment is good for New York, driving 105 kilometers per hour is the highway speed limit, or that a gallon of milk weighs 4 kilograms.

This also means knowledge of the metric prefixes and how they relate - by multiplication - similar units, like meter, kilometer and centimeter.

metric prefix	multiplier	exponent	symbol
Tera	1,000,000,000,000	10^{12}	T
Giga	1,000,000,000	10^{9}	G
Mega	1,000,000	10^{6}	M
kilo	1000	10^{3}	k
hecto	100	10^{2}	h
deka	10	10^{1}	da
none (base unit)	1	10^{0}	none
deci	0.1	10^{-1}	d
centi	0.01	10^{-2}	c
milli	0.001	10^{-3}	m
micro	0.00 000 1	10^{-6}	μ (mu)
nano	0.00 000 000 1	10^{-9}	n
pico	0.00 000 000 000 1	10^{-12}	p

Since the metric system multipliers basically count decimal places, they make many calculations easy to do, even without a calculator, because there are shortcuts to math with exponents.

- From smaller to larger units, move decimal point to left.
- From larger to smaller units, move decimal point to right.

There is a technique called dimensional analysis, where we use the exponents in fraction form to convert one related unit to another. This technique can also be used with non-exponent factors common in non-metric units. It is extremely important that students practice and learn this fraction technique, because it is used a lot in Chemistry.

scientific notation

When scientists measures everything, they often run into extremely large or exceptionally small things. The measurement will end up with many digits, especially zeroes, which will be hard to keep track of.

Scientists will abbreviate very long numbers, by counting decimal places and rewriting in scientific notation.

We always move the decimal point to between the first and second non-zero digits. Remember, whole numbers written without a decimal point, have it belonging at the end of the number. Large numbers have their decimal point moved to the left. Large numbers have their decimal point moved to the right. Numbers larger than one thousand (1000) or smaller than one-thousandth (0.001) are almost always written in scientific notation.

Scientific notation always looks like this:

$$x \times 10^y$$

The number in front of the multiplication sign is called the MANTISSA. It is the count - the important part. The EXPONENT is power of the ten. It counts the decimal places that the decimal point is moved. Large numbers have a positive number exponent. Small numbers have a negative number exponent.

To change from scientific notation back to a regular number, move the decimal point back to where it belongs, and fill in the missing decimal places with zeroes. Large numbers (positive exponent) have their decimal point moved back to the right. Small numbers (negative exponent) have their decimal point moved back to the left.

Scientific calculators can understand and use scientific notation. Numbers with more digits than can fit on the screen - usually ten - must be in scientific notation. Be careful, scientific notation is NOT A MULTIPLICATION; it is an abbreviation. DO NOT press the multiplication button, or enter ten, when you use scientific notation on your calculator. Your calculator will try to multiply, which is not what you're trying to do. Use the scientific notation button; usually labeled "EE", "EXP", or " $\times 10^y$ ". Your calculator's screen may not show the $\times 10$ either. There may only be an empty space or an "E" between the mantissa and exponent.

Your scientific calculator may also be able to convert between regular (usually called "floating notation") and scientific notation automatically. Check your calculator's manual for the correct button or menu.

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significant figures

Science is not math. In science, numbers do not count; they measure, and measurements have a precision limited by the quality of the measuring equipment.

The first part is COUNTING SIGNIFICANT FIGURES in a measurement. In CHM 01, there is no lab, so you will need to imagine making and writing down measurements.

There are rules for counting significant figures:

- All non-zero digits, 1 through 9, are significant.
- Leading zeroes (in front - to the left - of all other digits) are NEVER significant.
- Captured zeroes (in between other digits) are ALWAYS significant.
- Trailing zeroes (behind - to the right of - all other digits) are significant only if the number is written with a decimal point.

Special note: if a number is written in scientific notation, the entire mantissa is always significant.

The second part to significant figures is rounding off after a calculation. Calculators often give ten decimal places solutions. In science, most of the digits are irrelevant, because the original measurements don't have that many places. In science, the answer cannot be more precise than the information.

- When multiplying or dividing measurements, round off the answer to give the same number of significant figures as the LEAST NUMBER OF SIGNIFICANT FIGURES of the original measurements.
- When adding or subtracting measurements, round off the answer to give the same number of decimal places as the LEAST NUMBER OF DECIMAL PLACES of the original measurements.

Special note 1: whole numbers for calculation only (not a measurement) are EXACT; significant figures do not apply to them.

> Special note 2: if a multiple-step calculation combines addition/subtraction and multiplication/division, round off after each addition/subtraction or multiplication/division.

The rounding procedure is to ROUND UP if the next digit is GREATER THAN FIVE (5); ROUND DOWN if the next digit is LESS THAN FIVE (5); and ROUND TO AN EVEN DIGIT if the next digit is EXACTLY FIVE (5 or 500…). Note: this scientific rounding procedure is different than that taught in Math class.

Remember: calculators DO NOT know how to use significant figures.

Remember also the order of operations: if there are no parentheses powers (exponents) are calculated first, multiplication and division next, and addition and subtraction is last.

Chapter 1 Problems

Problem 1: How many grams are in 2.57 kilograms?

Problem 2: How many milligrams is the same as 0.032 grams?

Problem 3: How many decimeters are in 0.84 millimeters?

Problem 4: A time of 5.7 milliseconds is equivalent to _____ microseconds?

Problem 5: How many MegaPascals is equivalent to 63.9 kiloPascals?

Problem 6: A distance of 23.6 miles is the same as _____ kilometers? (1 mile ≈ 1.609 km)

Problem 7: How many milliLiters are in 2.45 quarts? (1 Liter ≈ 1.057 quarts)

Problem 8: How many calories are in 32.4 kiloJoules? (1 calorie ≈ 4.184 Joules)

Problem 9: How many inches are in 0.102 dekameters? (1 inch = 2.54 centimeters)

Problem 10: A distance of 22.1 meters is the same as how many feet? (1 inch = 2.54 centimeters)

Problem 11: An area of 5.44 square meters is equivalent to _____ square centimeters?

Problem 12: A "letter-size" sheet of paper is 8.5 inches by 11 inches. What is its area in centimeter squared? (1 inch = 2.54 centimeters)

Problem 13: How many cubic centimeters are in 6.31 cubic inches? (1 inch = 2.54 centimeters)

Problem 14: What is the volume of a baseball, in centimeter cubed, with a diameter of 2.9 inches? (1 inch = 2.54 centimeters, $V_{sphere} = \frac{4}{3}\pi r^3$)

Problem 15: A density of 7860 kilograms per cubic meter is equivalent to _____ grams per cubic centimeters? Remember: "per" means the measurement is already a fraction.

Problem 16: A speed of 70 miles per hour is equivalent to _____ meters per second? (1 mile = 5280 feet, 1 inch = 2.54 centimeters)

Problem 17:

Convert these measurements to scientific notation			
measurement	**scientific notation**	**measurement**	**scientific notation**
29,900 m		4201 km	
0.00452 mL		0.10940 mm	
20.9 g		8940 kg/m^3	
1,000,000 kg		0.00000559 μg	
0.399 s		982,000 cc	
0.0000285 K		607 °C	
5438 mg		25,600,000 Pa	
374.492 cm^2		0.0004764 cd	
2.56 μs		210,000,000 MJ	
325 mg		0.0035 nC	

Problem 18:

Convert these scientific notation measurements to regular "floating" notation			
scientific notation	**regular**	**scientific notation**	**regular**
7.8×10^3 cm^2		5.07×10^3 m/s	
3.35×10^{-4} mL		2.225×10^3 °C	
6.03×10^5 km		8.72×10^{-3} L	
2.0056×10^3 g		3.37×10^{-5} s	
2.91×10^{-2} kg		1.1×10^5 cm	
9.2772×10^6 m^3		6.25×10^{-2} ms	
1.96×10^{-1} g/cm^3		9.9874×10^2 MW	
9.10×10^{-5} cd		5.79×10^6 kJ	
1.3×10^1 Mg		4.4×10^{-6} mg	

Convert these scientific notation measurements to regular "floating" notation			
scientific notation	**regular**	**scientific notation**	**regular**
4.191×10^{-3} kN		7.07172×10^{3} km/s	

Problem 19:

how many significant figures are in each measurement?			
measurement	**significant figures**	**measurement**	**significant figures**
6.07×10^{-15} kg		28.003004 m	
0.003840 mL		0.1209 cm	
17.00 ms		5008.0 nm	
8×10^{8} km		0.000305 s	
463.8052 °C		103.07 K	
300 L		13,000 mT	
301 mg		7.908×10^{15} g	
400 nC		57,000. mol	
0.00480 rad		807.0 MN	
70.007 kJ		1.6720×10^{-4} W	

Problem 20: do the following calculations and round off the answer to proper significant figures:

a) $80.207 + 5.9 =$

b) $43.9 \div 8.342 =$

c) $\left(4.31 \times 10^{4}\right) + \left(2.9 \times 10^{1}\right) =$

d) $\left(3.34 \times 10^{-2}\right) \times \left(6.5 \times 10^{6}\right) =$

e) $\dfrac{1.95 \times 10^{-3}}{7.84256 \times 10^{2}} =$

f) $\frac{171.110 - 165.6}{55.2} =$

g) $\left(6.54 \times 10^3\right) \times \left(1.10 \times 10^2\right) - 7.00 \times 10^5 =$

h) $15.5^3 + 14.8 =$

i) $\frac{9.06 \times 4.888}{3.96782 \times 4.4} =$

j) $486 \div 36 =$

k) $187.5 + \frac{77.9}{3.4} =$

l) $5100. \times 312 \div 7.99 =$

m) $\left(3.20 \times 10^3\right) + 5.62 \times 7.3^2 =$

n) $\frac{56.2}{17} - \frac{190.}{2.50} =$

o) $\left(5.6 + 109.002\right) \div \left(510.2 - 497.1\right) =$

Chapter 1 Solutions

Solution 1: How many grams are in 2.57 kilograms?

$$kilo = 10^3$$
$$kg = 10^3\ g$$
$$\frac{2.57\ \cancel{kg}}{1} \times \frac{10^3\ g}{\cancel{kg}} =$$
$$2.57 \times 10^3\ g = 2570\ g$$

Solution 2: How many milligrams is the same as 0.032 grams?

$$milli = 10^{-3}$$
$$mg = 10^{-3} g$$
$$\frac{0.032\ \cancel{g}}{1} \times \frac{mg}{\cancel{10^{-3}\ g}} =$$
$$\frac{0.032}{10^{-3}\ g} = 32\ mg$$

Solution 3: How many decimeters are in 0.84 millimeters?

$$milli = 10^{-3} \qquad deci = 10^{-1}$$
$$mm = 10^{-3}\ m \qquad dm = 10^{-1}\ m$$
$$\frac{0.84\ \cancel{mm}}{1} \times \frac{10^{-3}\ \cancel{m}}{\cancel{mm}} \times \frac{dm}{10^{-1}\ \cancel{m}} =$$
$$\frac{0.84 \times 10^{-3}\ dm}{10^{-1}} = 0.0084\ dm$$

Solution 4: A time of 5.7 milliseconds is equivalent to _____ microseconds?

$$milli = 10^{-3} \qquad micro = 10^{-6}$$
$$ms = 10^{-3}\ s \qquad \mu s = 10^{-6}\ s$$
$$\frac{5.7\ \cancel{ms}}{1} \times \frac{10^{-3}\ \cancel{s}}{\cancel{ms}} \times \frac{\mu s}{10^{-6}\ \cancel{s}} =$$
$$\frac{5.7 \times 10^{-3}\ \mu s}{10^{-6}} = 5700\ \mu s$$

Solution 5: How many MegaPascals is equivalent to 63.9 kiloPascals?

$$kilo = 10^{3} \qquad Mega = 10^{6}$$
$$kPa = 10^{3}\ Pa \qquad MPa = 10^{6}\ Pa$$
$$\frac{63.9\ \cancel{kPa}}{1} \times \frac{10^{3}\ \cancel{Pa}}{\cancel{kPa}} \times \frac{MPa}{10^{6}\ \cancel{Pa}} =$$
$$\frac{63.9 \times 10^{3}\ MPa}{10^{6}} = 0.0639\ MPa$$

Solution 6: A distance of 23.6 miles is the same as _____ kilometers? (1 mile ≈ 1.609 km)

$$\frac{23.6\ \cancel{miles}}{1} \times \frac{1.609\ km}{\cancel{mile}} =$$
$$23.6 \times 1.609\ km \approx 38.0\ km$$

Solution 7: How many milliLiters are in 2.45 quarts? (1 Liter ≈ 1.057 quarts)

$$milli = 10^{-3}$$
$$mL = 10^{-3}\ L$$
$$\frac{2.45\ \cancel{qt}}{1} \times \frac{\cancel{L}}{1.057\ \cancel{qt}} \times \frac{mL}{10^{-3}\ \cancel{L}} =$$
$$\frac{2.45\ mL}{1.057 \times 10^{-3}} \approx 2320\ mL$$

Solution 8: How many calories are in 32.4 kiloJoules? (1 calorie ≈ 4.184 Joules)

$$kilo = 10^{3}$$
$$kg = 10^{3}\ g$$
$$\frac{32.4\ \cancel{kJ}}{1} \times \frac{10^{3}\ \cancel{J}}{\cancel{kJ}} \times \frac{cal}{4.184\ \cancel{J}} =$$
$$\frac{32.4 \times 10^{3}\ cal}{4.184} \approx 7740\ cal$$

Solution 9: How many inches are in 0.102 dekameters? (1 inch = 2.54 centimeters)

$$deka = 10^{1} \qquad centi = 10^{-2}$$
$$dam = 10^{1}\ m \qquad cm = 10^{-2}\ m$$
$$\frac{0.102\ \cancel{dam}}{1} \times \frac{10^{1}\ \cancel{m}}{\cancel{dam}} \times \frac{\cancel{cm}}{10^{-2}\ \cancel{m}} \times \frac{inch}{2.54\ \cancel{cm}} =$$
$$\frac{0.102 \times 10^{1}\ inch}{10^{-2} \times 2.54} =$$
$$\frac{1.02\ inch}{0.0254} \approx 40.2\ inch$$

Solution 10: A distance of 22.1 meters is the same as how many feet? (1 inch = 2.54 centimeters)

$$centi = 10^{-2}$$
$$cm = 10^{-2}\ m$$
$$\frac{22.1\ \cancel{m}}{1} \times \frac{\cancel{cm}}{10^{-2}\ \cancel{m}} \times \frac{\cancel{inch}}{2.54\ \cancel{cm}} \times \frac{feet}{12\ \cancel{inch}} =$$
$$\frac{22.1\ feet}{10^{-2} \times 2.54 \times 12} =$$
$$\frac{22.1\ feet}{0.3048} \approx 75.5\ feet$$

Solution 11: An area of 5.44 square meters is equivalent to _____ square centimeters?

$$centi = 10^{-2}$$
$$cm = 10^{-2}\ m$$
$$\frac{5.44\ m^2}{1} \times \left(\frac{cm}{10^{-2}\ m}\right)^2 =$$
$$\frac{5.44\ \cancel{m^2}}{1} \times \frac{cm^2}{10^{-4}\ \cancel{m^2}} =$$
$$\frac{5.44\ cm^2}{10^{-4}} = 54{,}400\ cm^2$$

Solution 12: A "letter-size" sheet of paper is 8.5 inches by 11 inches. What is its area in centimeter squared? (1 inch = 2.54 centimeters)

$$Area = length \times width$$
$$A = 11\ in \times\ 8.5\ in$$
$$A = 93.5\ in^2$$

$$\frac{93.5\ in^2}{1} \times \left(\frac{2.54\ cm}{in}\right)^2 =$$
$$\frac{93.5\ \cancel{in^2}}{1} \times \frac{6.45\ cm^2}{\cancel{in^2}} =$$
$$93.5 \times 6.45\ cm^2 \approx 603\ cm^2$$

Solution 13: How many cubic centimeters are in 6.31 cubic inches? (1 inch = 2.54 centimeters)

$$\frac{6.31\ in^3}{1} \times \left(\frac{2.54\ cm}{in}\right)^3 =$$
$$\frac{6.31\ \cancel{in^3}}{1} \times \frac{16.39\ cm^3}{\cancel{in^3}} =$$
$$6.31 \times 16.39\ cm^3 \approx 103\ cm^3$$

Solution 14: What is the volume of a baseball, in centimeter cubed, with a diameter of 2.9 inches? (1 inch = 2.54 centimeters, $V_{sphere} = \frac{4}{3}\pi r^3$)

$$V_{sphere} = \frac{4}{3}\pi r^3$$
$$V \approx \frac{4}{3}(3.14)\left(1.45\ in\right)^3$$
$$V \approx 12.8\ in^3$$

$$\frac{12.8\ in^3}{1} \times \left(\frac{2.54\ cm}{in}\right)^3 =$$
$$\frac{12.8\ \cancel{in^3}}{1} \times \frac{16.39\ cm^3}{\cancel{in^2}} =$$
$$12.8 \times 16.39\ cm^3 \approx 209\ cm^3$$

Solution 15: A density of 7860 kilograms per cubic meter is equivalent to _____ grams per cubic centimeters? Remember: “per” means the measurement is already a fraction.

$$kilo = 10^3 \qquad centi = 10^{-2}$$
$$kg = 10^3\ g \qquad cm = 10^{-2}\ m$$
$$\frac{7860\ kg}{m^3} \times \frac{10^3\ g}{kg} \times \left(\frac{10^{-2}\ m}{cm}\right)^3 =$$
$$\frac{7860\ \cancel{kg}}{\cancel{m^3}} \times \frac{10^3\ g}{\cancel{kg}} \times \frac{10^{-6}\ \cancel{m^3}}{cm^3} =$$
$$\frac{7860 \times 10^3 \times 10^{-6}\ g}{cm^3} = 7.86\ g/cm^3$$

Solution 16: A speed of 70 miles per hour is equivalent to _____ meters per second? (1 mile = 5280 feet, 1 inch = 2.54 centimeters)

$$centi = 10^{-2}$$
$$cm = 10^{-2}\ m$$
$$\frac{70\ \cancel{mile}}{\cancel{hr}} \times \frac{5280\ \cancel{feet}}{\cancel{mile}} \times \frac{12\ \cancel{inch}}{\cancel{feet}} \times \frac{2.54\ \cancel{cm}}{\cancel{inch}} \times \frac{10^{-2}\ m}{\cancel{cm}} \times \frac{\cancel{hr}}{60\ \cancel{min}} \times \frac{\cancel{min}}{60\ sec} =$$
$$\frac{70 \times 5280 \times 12 \times 2.54 \times 10^{-2}\ m}{60 \times 60\ sec} =$$
$$\frac{112{,}700\ m}{3600\ sec} \approx 31.3\ m/s$$

Note: for long complex calculations, you should multiply the numerator and the denominator separately, before dividing.

Solution 17:

Convert these measurements to scientific notation			
measurement	**scientific notation**	**measurement**	**scientific notation**
29,900 m	2.99×10^4 m	4201 km	4.201×10^3 km
0.00452 mL	4.52×10^{-3} mL	0.10940 mm	1.094×10^{-1} mm
20.9 g	2.09×10^1 g	8940 kg/m³	8.94×10^3 kg/m³
1,000,000 kg	1×10^6 kg	0.00000559 μg	5.59×10^{-6} μg
0.399 s	3.99×10^{-1} s	982,000 cc	9.82×10^5 cc
0.0000285 K	2.85×10^{-5} K	607 °C	6.07×10^2 °C
5438 mg	5.438×10^3 mg	25,600,000 Pa	2.56×10^7 Pa
374.492 cm²	3.74492×10^2 cm²	0.0004764 cd	4.764×10^{-4} cd
2.56 μs	2.56×10^0 μs	210,000,000 MJ	$21. \times 10^8$ MJ
325 mg	3.25×10^2 mg	0.0035 nC	3.5×10^{-3} nC

Solution 18:

Convert these scientific notation measurements to regular "floating" notation			
scientific notation	**regular**	**scientific notation**	**regular**
7.8×10^3 cm²	7800 cm³	5.07×10^3 m/s	5070 m/s
3.35×10^{-4} mL	0.000335 mL	2.225×10^2 °C	222.5 °C
6.03×10^5 km	603,000 km	8.72×10^{-3} L	0.00872 L
2.0056×10^3 g	2005.6 g	3.37×10^{-5} s	0.0000337 s
2.91×10^{-2} kg	0.0291 kg	1.1×10^5 cm	110,000 cm
9.2772×10^6 m³	9,277,200 m³	6.25×10^{-2} ms	0.0625 ms
1.96×10^{-1} g/cm³	0.196 g/cm³	9.9874×10^2 MW	998.74 MW
9.10×10^{-5} cd	0.0000910 cd	5.79×10^6 kJ	5,790,000 kJ
1.3×10^1 Mg	13 Mg	4.4×10^{-6} mg	0.0000044 mg
4.191×10^{-3} kN	0.004191 kN	7.07172×10^3 km/s	7071.72 km/s

Solution 19:

how many significant figures are in each measurement?			
measurement	**significant figures**	**measurement**	**significant figures**
6.07×10^{-15} kg	3 SF	28.003004 m	8 SF
0.003840 mL	4 SF	0.1209 cm	4 SF
17.00 ms	4 SF	5008.0 nm	5 SF
8×10^8 km	1 SF	0.000305 s	3 SF
463.8052 °C	7 SF	103.07 K	5 SF
300 L	1 SF	13,000 mT	2 SF
301 mg	3 SF	7.908×10^{15} g	4 SF
400 nC	1 SF	57,000. mol	5 SF
0.00480 rad	3 SF	807.0 MN	4 SF

how many significant figures are in each measurement?			
measurement	**significant figures**	**measurement**	**significant figures**
70.007 kJ	5 SF	1.6720×10^{-4} W	5 SF

Solution 20: do the following calculations and round off the answer to proper significant figures:

a) $80.207 + 5.9 \approx 86.1$

b) $43.9 \div 8.342 \approx 5.26$

c) $(4.31 \times 10^4) + (2.9 \times 10^1) \approx 4.31 \times 10^4$

d) $(3.34 \times 10^{-2}) \times (6.5 \times 10^6) \approx 2.2 \times 10^5$

e) $\dfrac{1.95 \times 10^{-3}}{7.84256 \times 10^2} \approx 2.49 \times 10^{-6}$

f) $\dfrac{171.110 - 165.6}{55.2} \approx \dfrac{5.5}{55.2} \approx 0.10$

g) $$\begin{aligned}(6.54 \times 10^3) \times (1.10 \times 10^2) - (7.00 \times 10^5) &\approx 7.19 \times 10^5 - 7.00 \times 10^5 \\ &\approx 719{,}000 - 700{,}000 \\ &\approx 1.9 \times 10^4\end{aligned}$$

h) $15.5^3 + 14.8 \approx 3720 + 14.8 \approx 3.73 \times 10^3$

i) $\dfrac{9.06 \times 4.888}{3.96782 \times 4.4} \approx 2.5$

j) $486 \div 36 = 13.5 \approx 14$

k) $187.5 + \dfrac{77.9}{3.4} \approx 187.5 + 23 \approx 210.5 \approx 210.$

l) $5100. \times 312 \div 7.99 \approx 1.99 \times 10^5$

m) $$\begin{aligned}(3.20 \times 10^3) + 5.62 \times 7.3^2 &\approx (3.20 \times 10^3) + 5.62 \times 53 \\ &\approx (3.20 \times 10^3) + (3.0 \times 10^2) \\ &\approx 3.50 \times 10^3\end{aligned}$$

n) $\dfrac{56.2}{17} - \dfrac{190.}{2.50} \approx 3.3 - 76.0 \approx -72.7$

o) $(5.6 + 109.002) \div (510.2 - 497.1) \approx 114.6 \div 13.1 \approx 8.75$

Chapter 2: What are chemicals?

"Chemistry is wonderful! I feel sorry for people who don't know anything about chemistry. They are missing an important source of happiness." Linus [Carl] Pauling (1901 – 1994) chemist

This is where the chemistry really begins. We will be throwing a couple of hundred chemistry terms at you. You must learn these vocabulary words - so that you can understand what Chemists are talking about. If you have trouble recognizing a vocabulary word/technical term in a homework problem, LOOK IT UP, until you can remember it.

What is matter?

Chemistry is the study of MATTER and its changes. What is matter and how does it behave?

- MATTER is anything that occupies space and can be touched and felt.
- Matter consists of PARTICLEs (can be divided into tiny individual pieces).
- The quantity of matter is usually measured by its MASS (related to, but *not* the same as, weight).
- An amount of matter is also measured by its CHARGE for electrical topics (more important in Physics).

There are three physical PHASEs of matter: SOLIDs, LIQUIDs and GASes.

- A solid has a definite size and a definite shape.
- A liquid has a definite size, but no definite shape. A liquid will flow to take the shape of the bottom of its container.
- A gas has neither a definite size nor shape. A gas will expand to take the size and shape of its container.

Special note: There is a rare, unusual fourth phase of matter: PLASMA, which is basically a superhot ionized gas.

PURE versus MIXTURE

There are two types of matter: PURE substances and MIXTUREs.

A pure substance is one specific chemical by itself.

A mixture is two or more pure substances placed physically together, in ANY proportion, that do NOT chemically combine to produce a new substance. A mixture can be separated back into its parts by physical (mechanical). This means Chemistry is NOT required to separate a mixture. This does not mean that the separation will be easy.

> A HETEROGENEOUS mixture has the different substances still distinguishable from each other.
>
> > Rocks, soils and clays are natural heterogeneous mixtures common in GEOLOGY.
>
> A HOMOGENOUS mixture mixes so well that you can no longer see the different substances in the mixture, even with a microscope.
>
> > Air and seawater are the two most important natural homogeneous mixtures in geology.
>
> The most important type of homogenous mixtures in chemistry are AQUEOUS SOLUTIONs - any chemical dissolved in water. Not everything can be mixed with water.
>
> > Except for aqueous solutions, we are not going to use mixtures much in class; most of our substances will be pure.
> >
> > Just be aware that in real life, pure substances are very rare; most real sustances are mixtures.

We will come back to mixtures later.

The PERIODIC TABLE

There are two types of pure chemicals: ELEMENTs and COMPOUNDs

The PERIODIC TABLE OF THE ELEMENTS lists all of the elements.

The Periodic Table is the major reference of chemistry. You must have one with you whenever you are doing chemistry - to learn to read the Table like a map. If you

understand the Table, you know a lot of chemistry. If you do not know the Table, you do not understand any chemistry.

There are 118 known elements; they are numbered 1 through 118 on the Table. There are 90 naturally occurring elements, plus 28 synthetic elements.

The first 36 (plus a few other) elements are the most important elements. MEMORIZE their names, abbreviations (symbols) and locations on the Table. Most of the symbols are the first one (or two) letters of the name. Note, the names of elements are not capitalized, but the first letter (only) of the symbol is always capitalized. You do not need to memorize any numbers, because you can just copy them from the Table.

Some of the elements have abbreviations that do not match their English names, because they have old Latin names not used in English, although several European languages - such as French and Russian - still use them:

English name	symbol	Latin name
sodium	Na	natrium
potassium	K	kallium
iron	Fe	ferrum
copper	Cu	cuprum
silver	Ag	argentum
tin	Sn	stannum
antimony	Sb	stibium
tungsten	W	wolfram
gold	Au	aurum
mercury	Hg	hydrargenum
lead	Pb	plumbum

METAL vs. NONMETAL: There is a step line drawn on the right side of the Periodic Table that separates METALs on the left, from NONMETALs on the right. Hydrogen is usually considered to be left of the line as a nonmetal, although it does have some metallic properties. The elements touching the step line are sometimes called SEMIMETALs (or METALLOIDs), because they are on the border, and they sometimes behave like metals and other times like nonmetals. Silicon and germanium are the most famous metalloids.

Metals are LUSTROUS (shiny), MALLEABLE (shatter resistant), DUCTILE (stretchable), hard, and electric and heat CONDUCTORs (can transfer electricity and heat). Most of the elements are metals, although most people have never heard of the rare ones.

Nonmetals are not: they are DULL, BRITTLE, non-ductile, soft, and electric and heat INSULATORs.

PERIODs and GROUPs: The Periodic Table arranges the elements into a grid of seven (7) rows and eighteen (18) columns.

The rows are called the Periods. The larger Period 5, 6 and 7 elements are rare (and expensive); we will not encounter them often, even in pencil-and-paper problems. "Kingsborough, and CUNY in general, is poor. You will not see any gold (which is in Period 6) in any Kingsborough chemistry lab unless you bring your own."

The columns are called Groups. There are 8 REPRESENTATIVE GROUPs, numbered Group 1A through 8A (1A and 2A on the left, 3A to 8A on the right). The middle section is treated as one big Group (technically, they are numbered Groups 1B to 8B, but don't worry about that).

The elements in the same Group (column) are chemically similar to each other - they are part of the same chemical family. Some of the Groups have family names to indicate their similarity:

- Group 1A are the ALKALI METALs;
- Group 2A are the ALKALI EARTH METALs;
- Group 6A are the CHALCOGENs;
- Group 7A are the HALOGENs;
- Group 8A are the NOBLE GASes. The noble gases are very unusual because they are INERT; they don't form chemical bonds - they don't do any chemistry.
- The entire middle section - the B Groups - are the TRANSITION METALs

Most of the elements are solids.

Two elements are liquids at ROOM TEMPERATURE ($\approx$ 20°C): mercury (Hg) and bromine (Br_2). Gallium (Ga) is also a liquid if it is warm.

There are two groups of elements that are normally gases:

• The DIATOMIC GASes are hydrogen (H_2), nitrogen (N_2), oxygen (O_2), fluorine (F_2), chlorine (Cl_2). Diatomic means they exist as paired atoms.

• The NOBLE GASes (the last column, Group 8A, on the Periodic Table) are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn).

ATOMS

Elements are made up of ATOMs - the smallest possible particle (piece) of an element is an atom.

Atoms are extremely tiny. Even with the world's most powerful microscopes - magnified ten million times - atoms are still just fuzzy blobs.

Atoms have parts; they can be broken into smaller particles - although not by chemical means. These smaller SUBATOMIC PARTICLES are called PROTONs, NEUTRONs and ELECTRONs.

> Protons (p^+) have a mass of approximately one (1) ATOMIC MASS UNIT (amu) and one (1) POSITIVE CHARGE.
>
> Neutrons (n^0) have a mass a little greater than a proton, but have zero (0) NEUTRAL CHARGE.
>
> Electrons (e^-) have a very small mass (approximately 1/1800 the mass of a proton) and one (1) NEGATIVE CHARGE - equal but opposite the proton charge.

Protons are the most important subatomic particle. The type of element is determined by counting the number of protons in its atoms. In other words: all of the atoms of the same element have the same number of protons, and different elements have atoms with a different number of protons.

> The number of protons in an element's atoms is called its ATOMIC NUMBER. Atomic number is abbreviated Z.
>
> The Periodic Table lists the elements in order of their atomic number. You are not required to memorize atomic numbers; you are supposed to look them up on the Periodic Table.

The number of electrons is equal to the number of protons in a normal NEUTRAL atom. Since protons and electrons have equal but opposite charge, atoms are neutral (zero) in total charge.

An ION is an abnormal atom that has gained or lost electrons from normal and is no longer neutral.

An ANION (ANN-eye-on) is an ion that has gained electrons and has a negative charge. Nonmetals normally form anions.

A CATION (CAT-eye-on) is an ion that has lost electrons and has a positive ion. Metals normally form cations.

Remember, since electrons have negative charge; ion charges seem to count in reverse - like signed numbers.

The first Group family trait we need you to learn is the pattern to the normal MONATOMIC ION CHARGE:

- Group 1A atoms normally form 1+ ions;
- Group 2A atoms normally form 2+ ions;
- Group 3A atoms normally form 3+ ions;
- Group 4A atoms normally form 4+ ions;
- Group 5A atoms normally form 3- ions;
- Group 6A atoms normally form 2- ions;
- Group 7A atoms normally form 1- ions;
- Group 8A atoms are inert and do not normally form ions.
- The B Group atoms do not have a simple charge pattern. Their charge is determined by context.

Note that ion charges are written number first, positive/negative sign last; opposite of a mathematical positive/negative number.

The number of neutrons in an atom depends on the ISOTOPE. Isotopes are different atoms of the same element (same number of protons), but different numbers of neutrons. Almost all of elements have have multiple naturally occurring isotopes.

If you need to the count of neutrons, you need extra information - you will be given the MASS NUMBER. The mass number of an atom is the sum of its protons and neutrons. Isotopes have the same atomic number, but have different mass numbers. Mass number is abbreviated A. Therefore, the number of neutrons in an atom is the mass number minus the atomic number ($n^0 = A - Z$).

Mass number or other isotope information is not on the Periodic Table. The AVERAGE ATOMIC MASS (or WEIGHT) of an element as written on the Periodic Table is the "weighted average" of all of the individual isotopic masses - NOT the mass of any individual atom. Average atomic mass is NOT the same as mass number.

Elements do not have the same ABUNDANCEs (do not have equal percentage splits) of their isotopes.

An ISOTOPIC MASS is the mass (weight) of one isotope of an element. Isotopic mass is NOT the same as mass number.

A NUCLIDE is the generic term for any isotope of any element.

Atoms have an ATOMIC STRUCTURE (a specific arrangement of its parts).

The protons and neutrons packed into a ball at the center of the atom called the NUCLEUS (plural is NUCLEI). Note, the word "nucleus" is also used in Biology, where it means the central organelle in an eukaryote cell holding the chromosomes.

The electrons are outside the nucleus; they ORBIT at different distances in ENERGY SHELLs (or ENERGY LEVELs).

Atoms are actually mostly empty space - the distance at which the electrons orbit is about one hundred thousand times the diameter of the nucleus.

This description is called the BOHR MODEL, after Niels Bohr, and will be discussed in much more detail in CHM 1100.

ATOMIC SYMBOLs are an abbreviation of a nuclide's proton/neutron/electron information - remember, scientists never write anything out in complete words.

Writing an ATOMIC SYMBOL (or ISOTOPIC SYMBOL):

step 1: Write the abbreviation of the element;

step 2: Write the element's atomic number (look it up on Periodic Table) at the bottom left corner;

step 3: Write the isotope's mass number (must be given to you) on the top left corner.

step 4: If it is an ion, write the charge number at the top right corner; otherwise leave that corner blank.

MOLECULES

Compounds combine two or more elements to make something new that behaves chemically different than the elements alone. Compounds are made up of molecules - the smallest possible particle of a compound is a molecule. Molecules are made of two or more atoms joined together by CHEMICAL BONDs. Molecules can be separated back into atoms by chemical means. Large, complex biologic molecules may contain millions of atoms. There are over 25 million known compounds. Bonding will be discussed in detail in CHM 11.

The CHEMICAL FORMULA (plural FORMULAE), or MOLECULAR FORMULA, of a compound counts the atoms that its molecule contains. A chemical formula writes each element contained in the compound using its symbol and counts the atoms of that element with a SUBSCRIPT (a number at the bottom right corner of each symbol). If there is no number written, the number is one (1). A subscript outside parentheses counts for all elements inside them. Think multiplication! In inorganic chemistry, the elements further to the left and up the Periodic Table are written before elements further to the right and down the Table.

> The LAW OF DEFINITE PROPORTIONS says that every specific compound has one specific count of atoms in its molecule, and therefore has one specific chemical formula.
>
> The LAW OF MULTIPLE PROPORTIONS says that specific elements may bond in different numbers of atoms to produce different compounds, and therefore the same set of elements may appear in more than one specific chemical formula.
>
> "When chemists write water as H_2O, we are saying that all water molecules contain two (2) atoms of hydrogen and one (1) atom of oxygen, three (3) atoms total; no more, no less. Any molecule that does not contain this exact count of atoms is not a water molecule. Hydrogen peroxide is a different chemical, with H_2O_2 as its formula. All hydrogen peroxide molecules have four (4) total atoms; two (2) of hydrogen and two (2) of oxygen. A water molecule is not the same as a hydrogen peroxide molecule, because they do not have the same exact count of atoms."

A chemical formula usually will NOT tell you which atom is bonded to which other atom in the molecule. It is possible to have two (or more) very different compounds with the same formula (especially, larger ones) because the bonding is arranged differently. These compounds are called ISOMERs. Isomers have the same molecular formula (count of atoms), but have different MOLECULAR STRUCTURE (arrangement of atoms). Isomers are not very important right now, but are extremely important in Organic Chemistry.

COMPOUND NOMENCLATURE

compound naming rules: using the IUPAC rules (the Stock system)

There are two major types of compounds: IONIC COMPOUNDs and COVALENT COMPOUNDs (also called MOLECULAR COMPOUNDs). Therefore, there are two basic sets of naming rules; plus special rules for special cases.

IONIC COMPOUND naming

Ionic compounds are generally metal and nonmetal. In other words: an element from the left side of the Periodic Table bonds with a second element from the right side. An ionic compound is made up of positive metallic cation and negative nonmetallic anion, where electrons are transferred from the metal to the nonmetal.

If you have an ionic compound's formula, follow these steps for its official name:

step 1: name metal ion first and normally.

step 2: name nonmetal ion last, but switch the ending to -ide.

step 3: if using a polyatomic ion, use its name:

SO_4^{2-}	sulfate	$C_2H_3O_2^{-}$	acetate
SO_3^{2-}	sulfite	MnO_4^{-}	permanganate
NO_3^{-}	nitrate	CN^{-}	cyanide
NO_2^{-}	nitrite	O_2^{2-}	peroxide
CO_3^{2-}	carbonate	OH^{-}	hydroxide
PO_4^{3-}	phosphate	NH_4^{+}	ammonium

A polyatomic ion is a group of atoms that is an ion as a whole group, not as individual atoms, which is why the group has its own name.

You must MEMORIZE the names of the important polyatomic ions, because they are NOT on the Periodic Table - they are not elements. Begin with the above 12, because they are the most common - in pencil-and-paper problems, as well as in real chemistry. There are hundreds of other polyatomic ions. Your professor will want you to learn some of them.

step 4: if using a transition metal ion, determine its charge and write that in Roman numerals. Tin and lead are considered transition metals, even though they are in Group 4A. Silver and zinc do not need Roman numerals, because they have only one charge each: Ag^{+} and Zn^{2+}.

Special note 1: an ionic compound name NEVER counts the ions.

Special note 2: the traditional (old) names of transition metal ions are still used by non-chemists. These are the most common traditional names:

ion	**IUPAC name**	**traditional name**
Fe^{2+}	iron(II)	ferrous
Fe^{3+}	iron(III)	ferric
Cu^{+}	copper(I)	cuprous
Cu^{2+}	copper(II)	cupric

Special cases of ionic compounds:

ACIDs are a special type of ionic compound where the cation is H^{+} and it is dissolved in water (in aqueous solution - abbreviated aq)

There two subtypes of acids:

BINARY ACID - two part acid, with no oxygen

format is always: HX = hydro____ic acid,
where the blank is filled by dropping the last syllable of the anion.

OXO-ACIDs - with oxo-ions - a polyatomic ion with oxygen

step 1: don’t say hydro.

step 2: name the oxo-ion, but switch -ate to -ic and -ite to -ous.

step 3: say acid.

METAL HYDRIDEs: (anion is H^-)

step 1: name metal cation first, following the normal ionic compound rules.

step 2: say hydride.

HYDRATEs: (ionic compound with adsorbed water - some compounds absorb moisture from the air)

The formula of a hydrate separates the normal ionic compound from the water molecules with a dot.

step 1: name ionic compound following the normal ionic compound rules.

step 2: count the water molecules with a prefix:

1 - mono	6 - hexa
2 - di	7 - hepta
3 - tri	8 - octa
4 - tetra	9 - nona
5 - penta	10 - deca

step 3: say hydrate

COVALENT COMPOUND (also called MOLECULAR COMPOUND) naming

Covalent compounds are generally nonmetal and another nonmetal. In other words: an element from the right side of the Periodic Table bonds with a second element from the right side. A covalent compounds has no ions.

nonmetal + nonmetal (no ions)

step 1: name nonmetal ion further left or down on Periodic Table first and normally.

step 2: name nonmetal ion further right or up on Periodic Table last, but switch ending to -ide.

These two rules are used to decide which of the two nonmetals is more important and gets to go first. This is not important to beginning students. Whichever nonmetal your professor gives you first, goes first; whichever one your professor gives you last, goes last.

step 3: count each nonmetal with a prefix:

1 - mono	6 - hexa
2 - di	7 - hepta
3 - tri	8 - octa
4 - tetra	9 - nona
5 - penta	10 - deca

Special note 1: drop mono for the first nonmetal only

Special note 2: a few well-known hydrogen-containing covalent compounds have traditional names that are grandfathered as exceptions to the normal IUPAC rules. The most important are water H_2O (not dihydrogen monoxide) and ammonia NH_3 (not trihydrogen mononitride).

Note: metal + metal is NOT a compound. It is a homogenous mixture (a solid solution) called an ALLOY. In engineering, the most important alloys are steels (iron alloys) and aluminum alloys. Since Kingsborough is a two-year college, with no metallurgy classes, we will not be studying alloys.

Chapter 2 Problems

Problem 1: Of the following elements: potassium, Mg, copper, oxygen, iodine, Ar, phosphorus, fluorine, Ag, Be, nitrogen, Co, hydrogen

which are a) a halogen; b) an alkali metal; c) a noble gas; d) in Period 4; e) in Period 3; f) a transition metal; g) a nonmetal?

It is possible to have more than one correct answer to each question, or have choices that are correct answers to more than one question, or have choices that are not correct answers to any question, but all questions have answers.

Problem 2: Of the following elements: Ca, strontium, tungsten, sulfur, oxygen, hydrogen, As, fluorine, Cd, zirconium, Si, zinc, helium

which are a) a chalcogen; b) an alkali earth metal; c) a diatomic gas; d) in Period 1; e) in Period 5; f) a transition metal; g) a metalloid?

It is possible to have more than one correct answer to each question, or have choices that are correct answers to more than one question, or have choices that are not correct answers to any question, but all questions have answers.

Problem 3:

Complete the table by filling in the blank cells according to the headings							
symbol	**atomic number**	**mass number**	**number of protons**	**number of neutrons**	**number of electrons**	**net charge**	**element name**
$^{56}_{26}Fe^{3+}$							
			47	60		0	
	20	42				2+	
			18	20	18		
		90	38		38		
				146		3+	americium
	83			126		5+	

Complete the table by filling in the blank cells according to the headings							
symbol	atomic number	mass number	number of protons	number of neutrons	number of electrons	net charge	element name
	35	81				1-	
		186			68		tungsten
	84	210			86		

Problem 4: Complete the table by writing the chemical formula of the ionic compound formed by the cations listed in the first column with the anions named in the top row in the intersecting cell:

	chloride	nitride	nitrite	nitrate	carbonate
sodium					
calcium					
chromium(II)					
chromium(III)					
ammonium					

Problem 5: Complete the table by writing the chemical formula of the ionic compound formed by the cations listed in the first column with the anions named in the top row in the intersecting cell:

	oxide	hydroxide	sulfite	sulfate	phosphate
magnesium					
aluminum					
iron(III)					
manganese(VI)					
potassium					

Problem 6: Complete the table by writing the chemical formula of the ionic compound formed by the cations listed in the first column with the anions named in the top row in the intersecting cell:

	acetate	**perchlorate**	**hydride**	**oxalate**	**dichromate**
barium					
cesium					
vanadium(V)					
tungsten(VI)					
lead(IV)					

Problem 7: Complete the table by writing the names for each of the following compound formulae:

formula	**name**
CuI	
CuI_2	
CoI_2	
P_4O_{10}	
Na_2CO_3	
$NaHCO_3$	
H_3PO_3 *(aq)*	
S_4N_4	
$SeCl_4$	
$NaClO$	
$BaCrO_4$	
NH_4NO_3	
$Sn_3(PO_4)_2$	
$HC_2H_3O_2$ *(aq)*	

formula	name
NH_4NO_2	
Co_2S_3	
ICl	
$Pb_3(PO_4)_2$	
$KClO_3$	
H_2SO_4 $_{(aq)}$	
SeF_4	
Sr_3N_2	
$Al_2(SO_3)_3$	
SnO_2	
NBr_3	
Na_2CrO_4	
SO_3	
HNO_3 $_{(aq)}$	
Mg_3N_2	
$HI_{(aq)}$	
$Cu_3(PO_4)_2$	
$CuSO_4 \bullet 5H_2O$	
$Co(NO_3)_2 \bullet 6H_2O$	
CrH_3	
$NiBr_2 \bullet 3H_2O$	
$ZnSO_4 \bullet 7H_2O$	
$Na_2SO_4 \bullet H_2O$	
$HClO_{(g)}$	
NaBr	

formula	name
ClF_4	
CS_2	
$LiC_2H_3O_2$	
PF_3	
S_2F_6	
Rb_2O	
CaS	
AlI_3	
$Pb_3(PO_4)_4 \bullet 6H_2O$	
$HF_{(g)}$	
$AsBr_3$	
$H_2Te_{(aq)}$	
P_2O_5	
SiO_2	
$HF_{(aq)}$	
NiH_2	

Problem 8: Complete the table by writing the formulae for each of the following compound names:

name	formula
chromium(VI) oxide	
disulfur dichloride	
nickel(II) fluoride	
potassium hydrogen phosphate	
aluminum nitride	

name	formula
ammonia	
manganese(IV) sulfide	
sodium dichromate	
ammonium sulfite	
carbon tetraiodide	
ammonium hydrogen phosphate	
mercury(I) sulfide	
silicon dioxide	
sodium sulfite	
aluminum hydrogen sulfate	
nitrogen trichloride	
hydrobromic acid	
bromous acid	
perbromic acid	
potassium hydrogen sulfide	
zinc(II) nitrate hexahydrate	
calcium iodide	
cesium perchlorate	
rubidium nitrite	
potassium sulfide	
sodium sulfate decahydrate	
sodium hydrogen sulfide	
magnesium phosphate	
calcium hydrogen phosphate	
potassium dihydrogen phosphate	

name	formula
iodine heptafluoride	
ammonium sulfate	
silver perchlorate	
boron trichloride	
copper(I) carbonate	
calcium sulfate monohydrate	
magnesium chloride hexahydrate	

Chapter 2 Solutions

Solution 1: Of the following elements: potassium, Mg, copper, oxygen, iodine, Ar, phosphorus, fluorine, Ag, Be, nitrogen, Co, hydrogen

which are a) a halogen; b) an alkali metal; c) a noble gas; d) in Period 4; e) in Period 3; f) a transition metal; g) a nonmetal?

a) iodine and fluorine are halogens

b) potassium is an alkali metal

c) Ar and neon are noble gases

d) copper and Co are in Period 4

e) Mg and Ar are in Period 3

f) copper, Ag and Co are transition metals

g) oxygen, iodine, Ar, phosphorus, fluorine and neon are nonmetals

Solution 2: Of the following elements: Ca, strontium, tungsten, sulfur, oxygen, hydrogen, As, fluorine, Cd, zirconium, Si, zinc, helium

which are a) a chalcogen; b) an alkali earth metal; c) a diatomic gas; d) in Period 1; e) in Period 5; f) a transition metal; g) a metalloid?

a) sulfur is a chalcogen

b) Ca and strontium are alkali earth metals

c) oxygen, hydrogen and fluorine are diatomic gases

d) hydrogen and helium are in Period 1

e) Cd and zirconium are in Period 5

f) tungsten, Cd, zirconium and zinc are transition metals

g) Si is a nonmetal

Solution 3:

Complete the table by filling in the blank cells according to the headings							
symbol	atomic number	mass number	number of protons	number of neutrons	number of electrons	net charge	element name
$^{56}_{26}Fe^{3+}$	26	56	26	30	23	3+	iron
$^{107}_{47}Ag$	47	107	47	60	47	0	silver
$^{42}_{20}Ca^{2+}$	20	42	20	22	18	2+	calcium
$^{38}_{18}Ar$	18	38	18	20	18	0	argon
$^{90}_{38}Sr$	38	90	38	52	38	0	strontium
$^{241}_{95}Am^{3+}$	95	241	95	146	92	3+	americium
$^{209}_{83}Bi^{5+}$	83	209	83	126	78	5+	bismuth
$^{81}_{35}Br^{-}$	35	81	35	46	36	1-	bromine
$^{186}_{74}W^{6+}$	74	186	74	112	68	6+	tungsten
$^{210}_{84}Po^{2-}$	84	210	84	126	86	2-	polonium

Solution 4: Complete the table by writing the chemical formula of the ionic compound formed by the cations listed in the first column with the anions named in the top row in the intersecting cell:

	Cl^{-}	N^{3-}	NO_2^{-}	NO_3^{-}	CO_3^{2-}
Na^{+}	$NaCl$	Na_3N	$NaNO_2$	$NaNO_3$	Na_2CO_3
Ca^{2+}	$CaCl_2$	Ca_3N_2	$Ca(NO_2)_2$	$Ca(NO_3)_2$	$CaCO_3$
Cr^{2+}	$CrCl_2$	Cr_3N_2	$Cr(NO_2)_2$	$Cr(NO_3)_2$	$CrCO_3$
Cr^{3+}	$CrCl_3$	CrN	$Cr(NO_2)_3$	$Cr(NO_3)_3$	$Cr_2(CO_3)_3$
NH_4^{+}	NH_4Cl	$(NH_4)_3N$	NH_4NO_2	NH_4NO_3	$(NH_4)_2CO_3$

Solution 5: Complete the table by writing the chemical formula of the ionic compound formed by the cations listed in the first column with the anions named in the top row in the intersecting cell:

	O^{2-}	OH^-	SO_3^{2-}	SO_4^{2-}	PO_4^{3-}
Mg^{2+}	MgO	$Mg(OH)_2$	$MgSO_3$	$MgSO_4$	$Mg_3(PO_4)_2$
Al^{3+}	Al_2O_3	$Al(OH)_3$	$Al_2(SO_3)_3$	$Al_2(SO_4)_3$	$AlPO_4$
Fe^{3+}	Fe_2O_3	$Fe(OH)_3$	$Fe_2(SO_3)_3$	$Fe_2(SO_4)_3$	$FePO_4$
Mn^{6+}	MnO_3	$Mn(OH)_6$	$Mn(SO_3)_3$	$Mn(SO_4)_3$	$Mn(PO_4)_2$
K^+	K_2O	KOH	K_2SO_3	K_2SO_4	K_3PO_4

Solution 6: Complete the table by writing the chemical formula of the ionic compound formed by the cations listed in the first column with the anions named in the top row in the intersecting cell:

	$C_2H_3O_2^-$	ClO_4^-	H^-	$C_2O_4^{2-}$	$Cr_2O_7^{2-}$
Ba^{2+}	$Ba(C_2H_3O_2)_2$	$Ba(ClO_4)_2$	BaH_2	BaC_2O_4	$BaCr_2O_7$
Cs^+	$CsC_2H_3O_2$	$CsClO_4$	CsH	$Cs_2(C_2O_4)$	$Cs_2Cr_2O_7$
V^{5+}	$V(C_2H_3O_2)_5$	$V(ClO_4)_5$	VH_5	$V_2(C_2O_4)_5$	$V_2(Cr_2O_7)_5$
W^{6+}	$W(C_2H_3O_2)_6$	$W(ClO_4)_6$	WH_6	$W(C_2O_4)_3$	$W(Cr_2O_7)_3$
Pb^{4+}	$Pb(C_2H_3O_2)_4$	$Pb(ClO_4)_4$	PbH_4	$Pb(C_2O_4)_2$	$Pb(Cr_2O_7)_2$

Solution 7: Complete the table by writing the names for each of the following compound formulae:

formula	name
CuI	copper(I) iodide
CuI_2	copper(II) iodide
CoI_2	cobalt(II) iodide
P_4O_{10}	tetraphosphorus decaoxide

formula	**name**
Na_2CO_3	sodium carbonate
$NaHCO_3$	sodium hydrogen carbonate
H_3PO_3 *(aq)*	phosphorous acid
S_4N_4	tetrasulfur tetranitride
$SeCl_4$	selenium tetrachloride
$NaClO$	sodium hypochlorite
$BaCrO_4$	barium chromate
NH_4NO_3	ammonium nitrate
$Sn_3(PO_4)_2$	tin(II) phosphate
$HC_2H_3O_2$ *(aq)*	acetic acid
NH_4NO_2	ammonium nitrite
Co_2S_3	cobalt(III) sulfide
ICl	iodine monochloride
$Pb_3(PO_4)_2$	lead(II) phosphate
$KClO_3$	potassium chlorate
H_2SO_4 *(aq)*	sulfuric acid
SeF_4	selenium tetrafluoride
Sr_3N_2	strontium nitride
$Al_2(SO_3)_3$	aluminum sulfite
SnO_2	tin(IV) oxide
NBr_3	nitrogen tribromide
Na_2CrO_4	sodium chromate
SO_3	sulfur trioxide
HNO_3 *(aq)*	nitric acid
Mg_3N_2	magnesium nitride

formula	name
$HI_{(aq)}$	hydroiodic acid
$Cu_3(PO_4)_2$	copper(II) phosphate
$CuSO_4 \bullet 5H_2O$	copper(II) sulfate pentahydrate
$Co(NO_3)_2 \bullet 6H_2O$	cobalt(II) nitrate hexahydrate
CrH_3	chromium(III) hydride
$NiBr_2 \bullet 3H_2O$	nickel(II) bromide trihydrate
$ZnSO_4 \bullet 7H_2O$	zinc sulfate heptahydrate
$Na_2SO_4 \bullet H_2O$	sodium sulfate monohydrate
$HClO_{(g)}$	hydrogen hypochlorite
NaBr	sodium bromide
ClF_4	chlorine tetrafluoride
CS_2	carbon disulfide
$LiC_2H_3O_2$	lithium acetate
PF_3	phosphorus trifluoride
S_2F_6	disulfur hexafluoride
Rb_2O	rubidium oxide
CaS	calcium sulfide
AlI_3	aluminum iodide
$Pb_3(PO_4)_4 \bullet 6H_2O$	lead(IV) phosphate hexahydrate
$HF_{(g)}$	hydrogen fluoride
$AsBr_3$	arsenic bromide
$H_2Te_{(aq)}$	hydrotelluric acid
P_2O_5	diphosphorus pentaoxide
SiO_2	silicon dioxide
$HF_{(aq)}$	hydrofluoric acid

formula	name
NiH_2	nickel(II) hydride

Solution 8: Complete the table by writing the formulae for each of the following compound names:

name	formula
chromium(VI) oxide	Cr_2O_3
disulfur dichloride	S_2Cl_2
nickel(II) fluoride	NiF_2
potassium hydrogen phosphate	K_2HPO_4
aluminum nitride	AlN
ammonia	NH_3
manganese(IV) sulfide	MnS_2
sodium dichromate	$Na_2Cr_2O_7$
ammonium sulfite	$(NH_4)_2SO_3$
carbon tetraiodide	CI_4
ammonium hydrogen phosphate	$(NH_4)_2HPO_4$
mercury(I) sulfide	Hg_2S_2
silicon dioxide	SiO_2
sodium sulfite	Na_2SO_3
aluminum hydrogen sulfate	$Al(HSO_4)_3$
nitrogen trichloride	NCl_3
hydrobromic acid	$HBr_{(aq)}$
bromous acid	$HBrO_{2\ (aq)}$
perbromic acid	$HBrO_{4\ (aq)}$
potassium hydrogen sulfide	KHS

name	formula
zinc(II) nitrate hexahydrate	$Zn(NO_3)_2 \bullet 6H_2O$
calcium iodide	CaI_2
cesium perchlorate	$CsClO_4$
rubidium nitrite	$RbNO_2$
potassium sulfide	K_2S
sodium sulfate decahydrate	$Na_2SO_4 \bullet 10H_2O$
sodium hydrogen sulfide	$NaHS$
magnesium phosphate	$Mg_3(PO_4)_2$
calcium hydrogen phosphate	$CaHPO_4$
potassium dihydrogen phosphate	KH_2PO_4
iodine heptafluoride	IF_7
ammonium sulfate	$(NH_4)_2SO_4$
silver perchlorate	$AgClO_4$
boron trichloride	BCl_3
copper(I) carbonate	Cu_2CO_3
copper(II) sulfate monohydrate	$CuSO_4 \bullet H_2O$
magnesium chloride hexahydrate	$MgCl_2 \bullet 6H_2O$

Chapter 3: the mole and chemical reactions

Chemical reactions

Chemicals can change. A chemical change is called a chemical reaction.

• When describing a chemical reaction, we write a CHEMICAL EQUATION.

• A chemical equation is read from left to right (just as all writing in Western culture normally is).

• The REACTANTs are the chemicals the reaction starts with, and is on the left side of the equation.

• The PRODUCTs are the new and different chemicals the reaction finishes with, and is on the right side of the equation.

• If there is more than one reactant or product, they are separated by PLUS (+) signs.

• The formulae of each compound may also have a PHASE SYMBOL attached to them as an extra subscript: (s) for solid, (l) for liquid, (g) for gas or (aq) for aqueous solution.

• The reactants and products are separated by a right pointing ARROW. The arrow is read "reacts to yield" (or "produce") and indicates that the reactants change into products.

• The COEFFICIENT (whole number) to the immediate left of each chemical formula counts the amount of that chemical needed in the reaction. If there is no number written, it is one (1).

Right now, you are not responsible for knowing many reactions, but some basic reaction types are:

COMBINATION (or SYNTHESIS) reactions describe the creation of a larger or more complex compound from smaller or simpler chemicals, especially elements.

$$\text{Ex 1:}\quad \mathrm{N}_{2\,(g)} + 3\,\mathrm{H}_{2\,(g)} \longrightarrow 2\,\mathrm{NH}_{3\,(g)}$$

$$\text{Ex 2:}\quad 2\,\mathrm{SO}_{2\,(g)} + \mathrm{O}_{2\,(g)} \longrightarrow 2\,\mathrm{SO}_{3\,(g)}$$

DECOMPOSITION reactions describe the breaking apart of a larger or more complex molecule into smaller or simpler ones, especially elements (usually by applying heat).

$$\text{Ex 1:}\quad 2\,NaN_{3\,(s)} \longrightarrow 2\,Na_{(s)} + 3\,N_{2\,(g)}$$

$$\text{Ex 2:}\quad 2\,KClO_{3\,(s)} \longrightarrow 2\,KCl_{(s)} + 3\,O_{2\,(g)}$$

COMBUSTION reactions. Combustion means burning with oxygen. Most hydrocarbon compounds burn by reacting completely with oxygen to produce carbon dioxide and water vapor (plus extra stuff sometimes).

$$\text{Ex 1:}\quad 2\,C_2H_{2\,(g)} + 5\,O_{2\,(g)} \longrightarrow 4\,CO_{2\,(g)} + 2\,H_2O_{(l)}$$

$$\text{Ex 2:}\quad 2\,CH_3CH(OH)CH_{3\,(l)} + 9\,O_{2\,(l)} \longrightarrow 6\,CO_{2\,(g)} + 8\,H_2O_{(l)}$$

BALANCING CHEMICAL EQUATIONS

molecules can change, atoms do not change

The LAW OF CONSERVATION OF MATTER says that matter cannot be created or destroyed by chemical means - matter can only be changed from one form to another. When chemicals react, their molecules change but the atoms (and their protons, neutrons and electrons) do not change - the atoms of matter are only reshuffled into new molecules. The number of atoms must remain the same. Atoms cannot disappear into nothingness, nor can they appear from nothingness.

BALANCING CHEMICAL EQUATIONS means counting the atoms of each element on the reactant and product sides of the equation to see if they are equal. If they are not, correct the count to make them equal.

“The general procedure for balancing most chemical equations is to check the count of each element in the equation, comparing back and forth between the reactants and products, one at a time. Remember, the arrow is read as an equal sign. I recommend two rules that works for most equations:

Rule 1: You are not allowed to change subscripts. To make a correction, use a COEFFICIENT. Write a number in front of the compound’s formula to *multiply* an atom to the correct count. Remember that a coefficient multiplies *all* the elements in the compound.

Rule 2: Do not begin with oxygen or hydrogen. Instead, begin balancing with a metal. Next, switch to a nonmetal. Keep alternating between metals and nonmetals until they are done. Hydrogen is next to last; oxygen is balanced absolutely last.

$$\text{Ex:} \quad \_\ C_2H_5OH_{(l)} + \_\ O_{2\,(g)} \longrightarrow \_\ CO_{2\,(g)} + \_\ H_2O_{(l)}$$

first is metal; none, skip

second is nonmetal; C

$$\_\ C_2 \neq \_\ C$$
$$\underline{1}\ C_2 = \underline{2}\ C$$

$$\underline{1}\ C_2H_5OH_{(l)} + \_\ O_{2\,(g)} \longrightarrow \underline{2}\ CO_{2\,(g)} + \_\ H_2O_{(l)}$$

next is H

$$\underline{1}\ (H_5\ H) \neq \_\ H_2$$
$$\underline{1}\ H_6 = \underline{3}\ H_2$$

$$\underline{1}\ C_2H_5OH_{(l)} + \_\ O_{2\,(g)} \longrightarrow \underline{2}\ CO_{2\,(g)} + \underline{3}\ H_2O_{(l)}$$

last is O

$$\underline{1}\ O + \_\ O_2 \neq \underline{2}\ O_2 + \underline{3}\ O$$
$$\underline{1}\ O + \underline{3}\ O_2 = \underline{2}\ O_2 + \underline{3}\ O$$

$$\underline{1}\ C_2H_5OH_{(l)} + \underline{3}\ O_{2\,(g)} \longrightarrow \underline{2}\ CO_{2\,(g)} + \underline{3}\ H_2O_{(l)}$$

Special note 1: Sometimes these rules end up giving fraction coefficients. Although, mathematically balanced, fractions are considered inelegant for most equations in chemistry. We want WHOLE NUMBER coefficients only. You are to multiply all the coefficients by the denominator to change them all to whole numbers. The equation is incomplete if you leave fraction coefficients.

Special note 2: Sometimes these rules end up impossibly messy to balance coefficients. If that happens, try balancing the oxygen first, instead of last. When in doubt, start with elements that appear once on each of the equation.

It is important that you practice balancing chemical equations, because it is a fundamental chemistry skill. If, by the end of the term, it takes you more than one minute to balance an equation, you are taking too long.

the mole, Avogadro's Number and molar mass

Chemical reactions take place atom-by-atom and molecule-by-molecule. However, since individual atoms and molecules are extremely tiny, it is to impractical manipulate individual atoms and molecules. Without a million dollars worth of equipment, it is impossible to pick up one atom of this and mix it with two molecules of that.

The MOLE is the UNIT of measurement for the quantity (amount) of a chemical. When you measure the amount of a chemical properly, you don't say the mass. Mass is a convenience in chemistry.

Chemists need to compare the numbers of atoms and molecules directly. A mole is a count of atoms, molecules or other particles. The best analogy is with a "dozen". If you have a dozen eggs, you know you have twelve (12) eggs. A dozen donuts is twelve donuts. A dozen of anything is twelve of those things, because the count for a dozen is twelve by definition.

A mole works the same way, except the count is not twelve. Instead, the mole count is Avogadro's Number - six hundred and two sextillion, two hundred quintillion (602,200,000,000,000,000,000,000) or, in SCIENTIFIC NOTATION:

$$1 \text{ mole of anything} = 6.022\times10^{23} \text{ particles of those things}$$

particle normally means atoms (for elements) or molecules (for compounds)

$$1 \text{ mol Fe (an element)} = 6.022\times10^{23} \text{ Fe atoms}$$

$$1 \text{ mol } CO_2 \text{ (a compound)} = 6.022\times10^{23}\ CO_2 \text{ molecules}$$

However, weighing a chemical is much more convenient. (It is usually simple to place something on a balance.) Therefore, what is the moles to grams conversion - what is the MOLAR MASS of a chemical?

The molar mass is the mass value on the Periodic Table. There are two important numbers given for every element on the Table - the whole number is the atomic number, the number with decimal places is the average atomic mass, which is also the molar mass. Remember, a compound's molar mass is the sum of all its elements.

Ex: 1 mol Fe (an element) = 55.85 g Fe

Ex: 1 mol CO_2 (a compound) = 44.01 g CO_2

$$\begin{array}{rl} & CO_2 \\ C & = 12.01 \\ O_2 = 16.00 \times 2 & = 32.00 \\ & CO_2 = 44.01\ g/mol \end{array}$$

Avogadro's Number and molar mass can be used as conversion factors. Remember to round off for significant figures and use scientific notation is appropriate.

The mole ratio

Since moles are directly related to counts of atoms and molecules, balanced chemical equations can be reinterpreted to say that the coefficients count moles. This is called the MOLE RATIO.

$$C_2H_5OH_{(l)} + 3\ O_{2\,(g)} \longrightarrow 2\ CO_{2\,(g)} + 3\ H_2O_{(l)}$$

can be read as

$$1\ mol\ C_2H_5OH = 3\ mol\ O_2 = 2\ mol\ CO_2 = 3\ mol\ H_2O$$

$$2\,NH_{3\,(g)} + 3\,O_{2\,(g)} + 2\,CH_{4\,(g)} \longrightarrow 2\,HCN_{(g)} + 6\,H_2O_{(l)}$$

is equivalent to

$$2\,mol\,NH_{3\,(g)} = 3\,mol\,O_{2\,(g)} = 2\,mol\,CH_{4\,(g)} = 2\,mol\,HCN_{(g)} = 6\,mol\,H_2O_{(l)}$$

Empirical formulae

An empirical formula of a compound is its molecular formula with its subscript numbers simplified (factored) as far as possible. It keeps the correct ratios of the compound's elements, even though the exact numbers may no longer be correct.

I always say "When you pick up a rock, there's no nice label on it telling you what chemical it's made of." How can the formula of an unknown chemical be identified? One way is to separate the compound back into its elements. It is fairly simple, if you know what you are doing, to separate compounds and weigh their elements as a percentage. This is called a PERCENT COMPOSITION.

Finding the composition is lab work. Since this is a lecture question, you need to imagine doing the lab work. You are doing the "lab report" calculation part.

If you are given a percent composition, there is a step-by-step calculation to find the empirical formula.

step 1: assume 100 g sample and convert elements to moles

step 2: divide all the moles values by the smallest mole value to get whole numbers

Obviously, a molecular formula is more useful than an empirical formula, because it is the true count of atoms. However, it is not possible to determine a molecular formula without its molar mass; which used to be very difficult to figure out. (Nowadays, you can buy machines to do most of this work automatically.) Once you have the empirical formula, there are more calculations to find the molecular formula.

step 1: use the empirical formula to find empirical mass

step 2: divide the molar mass by the empirical formula to get the multiplier

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STOICHIOMETRY:

Stoichiometry is the chemistry calculation to answer the question: How much? How much of this chemical is needed to react in this reaction? How much of that chemical is produced by that reaction? How much of one chemical reacts with a certain amount of another chemical?

Stoichiometry problems are generally word problems, that never say the word "stoichiometry". That means you must interpret the ENGLISH!

When you read a stoichiometry problem, it must have three things:

1: A BALANCED CHEMICAL EQUATION. If an equation is given unbalanced, you MUST balance it before going on. If a reaction is described in English, you MUST interpret it into chemical formulae. You do not need to worry about what the reaction is used for, or why it is important in real life.

2: One chemical whose amount is GIVEN to you. This is what you start with. It does not need to be a reactant.

3: Another chemical whose amount is UNKNOWN, but is being asked for. This is what you need to solve for. It does not need to be a product.

If you do not have these exact three things, it is not a stoichiometry problem (or a least not a normal one)!

There is a step by step procedure to solve stoichiometry problems.

step 1: convert given to moles
step 2: convert given to unknown
step 3: convert unknown from moles

Notice, these are conversion calculations that use the same "dimensional analysis" fraction technique introduced back in Chapter 1. Different stoichiometry problems may skip some steps or add extra steps to these basic three steps.

$$grams \text{ given } \times \frac{moles \text{ given}}{molar\ mass \text{ given}} = moles \text{ given}$$

$$moles \text{ given } \times \frac{moles \text{ unknown}}{moles \text{ given}} = moles \text{ unknown}$$

$$moles \text{ unknown } \times \frac{molar\ mass \text{ unknown}}{moles \text{ unknown}} = grams \text{ unknown}$$

Notice how the answer of each step is passed on to start the next step.

Theoretical yield, actual yield, and percent yield

Since stoichiometry is a pencil-and-paper calculation, it assumes that a chemical reaction runs perfectly. It calculates the maximum possible amount of product. This is called the theoretical yield.

If you run the same reaction in the real world, you will likely produce a smaller amount (sometimes a lot smaller) as the actual yield.

The ration of actual yield to the theoretical yield can be written as the percent yield.

$$\%\ yield = \frac{actual\ yield}{theoretical\ yield} \times 100$$

Limiting and excess reagents

Limiting reagents is a special case of stoichiometry. In a chemical reaction with multiple reactants, the amounts of two (or more) reactants are given in the problem. Since a balanced chemical equation must obey a mole ratio, if random masses are given, the masses will not properly obey the ratio. There will be too much of one reactant, and too little of another - there are limiting and excess reagents. Identifying them adds an extra step to the normal stoichiometry procedure (four steps total).

I think that the identification procedure in most textbooks in unnecessarily complex, and I recommend doing it differently.

step 1: convert given to moles
step 1A: identify limiting/excess reagent - divide by mole count
step 2: convert given to unknown
step 3: convert unknown from moles

COMBUSTION ANALYSIS

In chemistry, analysis is any technique that measures compounds and their elements so that the compound can identified.

In real science, chemicals must be identified. When you pick up a rock, there's no nice label on it telling you what chemical it's made of. Chemistry ANALYSIS are the various lab techniques used to identify unknown chemicals. One common technique is COMBUSTION ANALYSIS. The combustion part means burning the chemical in lab and measuring the masses of all the products. The analysis part is the calculations used to determine the compound's empirical formula. Since this is a lecture question, you need to imagine the lab work. In lecture, you are doing the "lab report" calculation part.

The analysis takes advantage of conservation of mass to use a 3-step stoichiometry-like calculation to determine the mass composition of the unknown compound.

The procedure is:

step 1: convert carbon dioxide and water products to moles
step 2: convert the compound moles into separate carbon and hydrogen element moles
step 3: convert the carbon and hydrogen from moles

The mass composition is then used to determine the empirical formula using the technique learned earlier.

Chapter 3 Problems

Problem 1: Balance the following chemical equations with whole number coefficients only:

a) _ $C_3H_{8\,(g)}$ + _ $O_{2\,(g)}$ ⟶ _ $CO_{2\,(g)}$ + _ $H_2O_{(l)}$

b) _ $P_4O_{10\,(s)}$ + _ $H_2O_{(l)}$ ⟶ _ $H_3PO_{4\,(aq)}$

c) _ $CaCO_{3\,(s)}$ + _ $HNO_{3\,(aq)}$ ⟶ _ $Ca(NO_3)_{2\,(aq)}$ + _ $CO_{2\,(g)}$ + _ $H_2O_{(l)}$

d) _ $AlCl_{3\,(aq)}$ + _ $KOH_{(aq)}$ ⟶ _ $Al(OH)_{3\,(aq)}$ + _ $KCl_{(aq)}$

e) _ $Ca_{(s)}$ + _ $H_2O_{(l)}$ ⟶ _ $Ca(OH)_{2\,(aq)}$ + _ $H_{2\,(g)}$

f) _ $Fe_2(SO_4)_{3\,(s)}$ + _ $NH_{3\,(g)}$ + _ $H_2O_{(l)}$ ⟶ _ $Fe(OH)_{3\,(aq)}$ + _ $(NH_4)_2SO_{4\,(aq)}$

g) _ $CH_3OH_{(l)}$ + _ $O_{2\,(g)}$ ⟶ _ $CO_{2\,(g)}$ + _ $H_2O_{(l)}$

h) _ $Al_{(s)}$ + _ $Fe_3O_{4\,(s)}$ ⟶ _ $Al_2O_{3\,(aq)}$ + _ $Fe_{(s)}$

i) _ $Al_{(s)}$ + _ $HCl_{(aq)}$ ⟶ _ $AlCl_{3\,(aq)}$ + _ $H_{2\,(g)}$

j) _ $H_3PO_{3\,(aq)}$ ⟶ _ $H_3PO_{4\,(aq)}$ + _ $PH_{3\,(g)}$

Problem 2: Solid calcium phosphate and aqueous sulfuric acid solution react to give solid calcium sulfate. The other product is phosphoric acid solution. Write the balanced equation for the reaction using complete formulas, including phase labels.

Problem 3: Solid sodium metal reacts violently with water (it looks like it on fire), giving a solution of sodium hydroxide and releasing hydrogen gas. Write the balanced equation for the reaction using complete formulas, with their phase symbols.

Problem 4: When heated, aqueous solutions of ammonium chloride and barium hydroxide react to evolve ammonia gas. Barium chloride solution and water are also products. Write the balanced equation for the reaction, with phase labels; indicate that the reactants are heated.

Problem 5: When solid ammonium dichromate, $(NH_4)_2Cr_2O_7$, a vivid orange compound, is ignited, a spectacular, almost explosive, reaction occurs. The products are solid chromium(III) oxide, nitrogen gas, and water vapor. Write and balance the equation for the reaction using complete formulas, with their phase symbols.

Problem 6: A major constituent of ordinary glass is calcium silicate, $CaSiO_3$. The calcium silicate can be dissolved with hydrofluoric acid; producing a solution of calcium fluoride, silicon tetrafluoride gas and water. Write and balance the equation for the reaction using complete formulas, including their phase symbols.

Problem 7: What is the molar mass of magnesium metal?

Problem 8: What is the molar mass of nitrogen gas?

Problem 9: What is the molar mass of $KClO_3$?

Problem 10: What is the molar mass of $Ca(NO_3)_2$?

Problem 11: What is the molar mass of C_2H_5OH?

Problem 12: What is the molar mass of sodium carbonate?

Problem 13: What is the molar mass of iron(III) sulfate?

Problem 14: What is the mass of 4.29 moles of cobalt?

Problem 15: What is the mass of 7.92 mol $SrCl_2$?

Problem 16: How many moles is a sample of 4.55×10^{22} molecules of caffeine? The molecular formula of caffeine is $C_8H_{10}N_4O_2$.

Problem 17: What is the mass of 1.94×10^{22} lead atoms?

Problem 18: How many water molecules are in a 25.33 g ice cube?

Problem 19: What is the mass of 2.4×10^{23} acetone molecules? The molecular formula of acetone is C_3H_6O.

Problem 20: Acetaminophen is a pain reliever and fever reducer; used as the active ingredient in Tylenol and many over-the-counter cold medicines. Analysis shows that it is 63.54% carbon, 6.00% hydrogen, 9.27% nitrogen, and 21.16% oxygen by mass. What is the empirical formula of acetaminophen?

Problem 21: Caffeine is a mild stimulant that naturally occurs in coffee and tea, and is added to energy drinks and many sodas. It contains 49.48% carbon, 5.15% hydrogen, 28.87% nitrogen, and 16.49% oxygen by mass and has a molar mass of 194.2 g/mol. What are the empirical and molecular formulae of caffeine?

Problem 22: The primary component of gasoline is isooctane. The balanced equation for the combustion of isooctane is:

$$2\ C_8H_{18\ (l)}\ +\ 25\ O_{2\ (g)}\ \longrightarrow\ 16\ CO_{2\ (g)}\ +\ 18\ H_2O_{(l)}$$

What mass of carbon dioxide is released by the complete combustion of 1 gallon (2800 g) of gasoline?

Problem 23: Ordinary limestone (calcium carbonate) can be dissolved in a nitric acid solution according to the following equation:

$$CaCO_{3\ (s)}\ +\ 2\ HNO_{3\ (aq)}\ \longrightarrow\ Ca(NO_3)_{2\ (aq)}\ +\ CO_{2\ (g)}\ +\ H_2O_{(l)}$$

If the solution contains 100. g of nitric acid, what maximum mass of limestone could be dissolved?

Problem 24: The most important industrial element is iron. Over a billion tons of iron is refined annually worldwide, to make steel and build everything from washing machines to skyscrapers. Additional hundreds of millions of tons of iron is recycled. However, pure iron is virtually nonexistent in nature. Iron must be refined from iron ores. A high quality iron ore is the reddish-brown mineral called hematite, Fe_2O_3. Hematite can be smelted (heated with coke, a form of almost pure carbon made from coal) at ~1900 °C to produce almost pure iron. The process' overall equation is:

$$2\ Fe_2O_{3\ (s)}\ +\ 3\ C_{(s)}\ \xrightarrow{\Delta}\ 4\ Fe_{(l)}\ +\ 3\ CO_{2\ (g)}$$

If smelting 57.8 tons of hematite produces 37.3 tons of iron, what is the percent yield of iron?

Problem 25: Household ammonia (NH_3) and bleach ($NaOCl$) must never be mixed, because they will react and produce hydrazine (N_2H_4), a toxic gas. The balanced equation is:

$$2\ NH_{3\,(aq)} + NaOCl_{(aq)} \longrightarrow N_2H_{4\,(g)|} + NaCl_{aq} + H_2O_{(l)}$$

Suppose you ignore the warning labels, and combine 25.0 g NH_3 with 25.0 g NaOCl. Which reactant is the limiting reagent? What mass of N_2H_4 would be produced?

Problem 26: Lithium is in great demand today for the lithium-ion batteries that power our smartphones and electric cars. Much lithium is pumped up from underground salty water aquifers, and the potassium/sodium/lithium chlorides are concentrated by solar evaporation. The lithium is then reacted with sodium carbonate and precipitated as lithium carbonate, for further processing:

$$2\,LiCl_{(aq)} + Na_2CO_{3\,(aq)} \longrightarrow Li_2CO_{3\,(s)} + 2\,NaCl_{(aq)}$$

If 1.94×10^3 g LiCl reacts with 4.91×10^3 g Na_2CO_3, which reactant is the limiting reagent? What mass of Li_2CO_3 would be produced?

Problem 27: Millions of tons of hydrochloric acid are used every year for "metal pickling" - removing any rust or corrosion from metal surfaces - before final finishing. The reaction with iron(III) oxide is:

$$Fe_2O_{3\,(s)} + 6\,HCl_{(aq)} \longrightarrow 2\,FeCl_{3\,(aq)} + 3\,H_2O_{(l)}$$

If a steel sheet with 5.29 g Fe_2O_3 rust is pickled with 2.45 g HCl, would all the rust be removed? What mass of $FeCl_3$ would be produced? If the rust is the excess reagent, what mass of Fe_2O_3 would remain?

Problem 28: Benzene is a carcinogen that contaminates many old industrial sites, such as parts of the Brooklyn Navy Yard, because it was commonly used as a solvent, before its danger was understood. It is a hydrocarbon, containing only the elements carbon and hydrogen. If complete combustion of a 0.799 g benzene sample produces 2.701 g carbon dioxide and 0.553 g water, and its molar mass is 78.1 g/mol, what are the empirical and molecular formulae of benzene?

Problem 29: Para-cresol, a substance used as a disinfectant, is a molecule that contains the elements carbon, hydrogen, and oxygen. Complete combustion of a 0.345 g sample of p-cresol produced 0.983 g carbon dioxide and 0.230 g water. Determine the empirical formula for p-cresol.

Chapter 3 Solutions

Solution 1: Balance the following chemical equations with whole number coefficients only:

a) $\underline{1}\ C_3H_{8\ (g)} + \underline{5}\ O_{2\ (g)} \longrightarrow \underline{3}\ CO_{2\ (g)} + \underline{4}\ H_2O_{(l)}$

b) $\underline{1}\ P_4O_{10\ (s)} + \underline{6}\ H_2O_{(l)} \longrightarrow \underline{4}\ H_3PO_{4\ (aq)}$

c) $\underline{1}\ CaCO_{3\ (s)} + \underline{2}\ HNO_{3\ (aq)} \longrightarrow \underline{1}\ Ca(NO_3)_{2\ (aq)} + \underline{1}\ CO_{2\ (g)} + \underline{1}\ H_2O_{(l)}$

d) $\underline{1}\ AlCl_{3\ (aq)} + \underline{3}\ KOH_{(aq)} \longrightarrow \underline{1}\ Al(OH)_{3\ (aq)} + \underline{3}\ KCl_{(aq)}$

e) $\underline{1}\ Ca_{(s)} + \underline{2}\ H_2O_{(l)} \longrightarrow \underline{1}\ Ca(OH)_{2\ (aq)} + \underline{1}\ H_{2\ (g)}$

f) $\underline{1}\,Fe_2(SO_4)_{3\,(s)} + \underline{6}\,NH_{3\,(g)} + \underline{6}\,H_2O_{(l)} \longrightarrow \underline{2}\,Fe(OH)_{3\,(aq)} + \underline{3}\,(NH_4)_2SO_{4\,(aq)}$

g) $\underline{2}\ CH_3OH_{\ (l)} + \underline{3}\ O_{2\ (g)} \longrightarrow \underline{2}\ CO_{2\ (g)} + \underline{4}\ H_2O_{(l)}$

h) $\underline{8}\ Al_{(s)} + \underline{3}\ Fe_3O_{4\ (s)} \longrightarrow \underline{4}\ Al_2O_{3\ (aq)} + \underline{9}\ Fe_{(s)}$

i) $\underline{2}\ Al_{(s)} + \underline{6}\ HCl_{(aq)} \longrightarrow \underline{2}\ AlCl_{3\ (aq)} + \underline{3}\ H_{2\ (g)}$

j) $\underline{4}\ H_3PO_{3\ (aq)} \longrightarrow \underline{3}\ H_3PO_{4\ (aq)} + \underline{1}\ PH_{3\ (g)}$

Solution 2: Solid calcium phosphate and aqueous sulfuric acid solution react to give solid calcium sulfate. The other product is phosphoric acid solution. Write the balanced equation for the reaction using complete formulas, including phase labels.

$$Ca_3(PO_4)_{2\ (s)} + 3\ H_2SO_{4\ (aq)} \longrightarrow 3\ CaSO_{4\ (aq)} + 2\ H_3PO_{4\ (aq)}$$

Solution 3: Solid sodium metal reacts violently with water (it looks like it on fire), giving a solution of sodium hydroxide and releasing hydrogen gas. Write the balanced equation for the reaction using complete formulas, with their phase symbols.

$$2\ Na_{(s)} + 2\ H_2O_{(l)} \longrightarrow 2\ NaOH_{(aq)} + H_{2\ (g)}$$

Solution 4: When heated, aqueous solutions of ammonium chloride and barium hydroxide react to evolve ammonia gas. Barium chloride solution and water are also products. Write the balanced equation for the reaction, with phase labels; indicate that the reactants are heated.

$$2\ NH_4Cl_{(aq)} + Ba(OH)_{2\ (aq)} \xrightarrow{\Delta} 2\ NH_{3\ (g)} + BaCl_{2\ (aq)} + 2\ H_2O_{(l)}$$

Solution 5: When solid ammonium dichromate, $(NH_4)_2Cr_2O_7$, a vivid orange compound, is ignited, a spectacular, almost explosive, reaction occurs. The products are solid chromium(III) oxide, nitrogen gas, and water vapor. Write and balance the equation for the reaction using complete formulas, with their phase symbols.

$$(NH_4)_2Cr_2O_{7\ (s)} \longrightarrow Cr_2O_{3\ (s)} + N_{2\ (g)} + 4\ H_2O_{(l)}$$

Solution 6: A major constituent of ordinary glass is calcium silicate, $CaSiO_3$. The calcium silicate can be dissolved with hydrofluoric acid; producing a solution of calcium fluoride, silicon tetrafluoride gas and water. Write and balance the equation for the reaction using complete formulas, including their phase symbols

$$CaSiO_{3\ (s)} + 6\ HF_{(aq)} \longrightarrow CaF_{2\ (aq)} + SiF_{4\ (g)} + 3\ H_2O_{(l)}$$

Solution 7: What is the molar mass of magnesium metal?

Mg = 24.31 g/mol (straight from Periodic Table)

Solution 8: What is the molar mass of nitrogen gas?

nitrogen is diatomic - N_2

$$N_2 = 14.01 \times 2 = 28.02\ g/mol$$

Solution 9: What is the molar mass of $KClO_3$

$$\begin{aligned} &KClO_3 \\ K &= 39.10 \\ Cl &= 35.45 \\ O_3 = 16.00 \times 3 &= 48.00 \\ KClO_3 &= 122.55\ g/mol \end{aligned}$$

Solution 10: What is the molar mass of $Ca(NO_3)_2$?

$$
\begin{aligned}
&\quad Ca(NO_3)_2 \\
Ca &\qquad\qquad\quad = 40.08 \\
(N)_2 &= 14.01 \times 2 = 28.02 \\
(O_3)_2 &= 16.00 \times 6 = 96.00 \\
&Ca(NO_3)_2 = 164.10\ g/mol
\end{aligned}
$$

Solution 11: What is the molar mass of C_2H_5OH?

$$
\begin{aligned}
&C_2H_5OH \\
C_2 &= 12.01 \times 2 = 24.02 \\
H_5 &= 1.008 \times 5 = \ \ 5.040 \\
O &\qquad\qquad\ \ = 16.00 \\
H &\qquad\qquad\ \ = \ \ 1.008 \\
&C_2H_5OH \approx 46.07\ g/mol
\end{aligned}
$$

Solution 12: What is the molar mass of sodium carbonate?

molecular formula is Na_2CO_3

$$
\begin{aligned}
&Na_2CO_3 \\
Na_2 &= 22.99 \times 2 = \ 45.98 \\
C &\qquad\qquad\ \ = \ 12.01 \\
O_3 &= 16.00 \times 3 = \ 48.00 \\
&Na_2CO_3 = 105.99\ g/mol
\end{aligned}
$$

Solution 13: What is the molar mass of iron(III) sulfate?

molecular formula is $Fe_2(SO_4)_3$

$$
\begin{aligned}
&Fe_2(SO_4)_3 \\
Fe_2 &= 55.85 \times 2 = 111.7 \\
(S)_3 &= \ 32.07 \times 3 = \ 96.21 \\
(O_4)_3 &= 16.00 \times 12 = 192.0 \\
&Fe_2(SO_4)_3 \approx 399.9\ g/mol
\end{aligned}
$$

Solution 14: What is the mass of 4.29 moles of cobalt?

molar mass is 1 mol Co = 58.93 g Co
(Avogadro's Number is not needed, because atoms/molecules is not part of this problem)

$$4.29 \; \cancel{mol\ Co} \times \frac{58.93 \; g \; \text{Co}}{1 \; \cancel{mol\ Co}} =$$
$$4.29 \times 58.93 \; g \; \text{Co} \approx 253 \; g \; \text{Co}$$

Solution 15: What is the mass of 7.92 mol $SrCl_2$?

$SrCl_2$
Sr = 87.62
$Cl_2 = 35.45 \times 2 = 70.90$
$SrCl_2 = 158.52 \; g/mol$

$$7.92 \; \cancel{mol\ SrCl_2} \times \frac{158.20 \; g \; SrCl_2}{1 \; \cancel{mol\ SrCl_2}} =$$
$$7.92 \times 158.20 \; g \; SrCl_2 \approx 1.25 \times 10^3 \; g \; SrCl_2$$

Solution 16: How many moles is a sample of 4.55×10^{22} molecules of caffeine? The molecular formula of caffeine is $C_8H_{10}N_4O_2$.

1 mol $C_8H_{10}N_4O_2$ = 6.022×10^{23} molecules $C_8H_{10}N_4O_2$ (Avogadro's Number)
(molar mass is not needed, because mass is not part of this problem)

$$4.55 \times 10^{22} \; \cancel{molecules\ C_8H_{10}N_4O_2} \times \frac{1 \; mol \; C_8H_{10}N_4O_2}{6.022 \times 10^{23} \; \cancel{molecules\ C_8H_{10}N_4O_2}} =$$
$$= \frac{4.55 \times 10^{22} \; mol \; C_8H_{10}N_4O_2}{6.022 \times 10^{23}}$$
$$\approx 7.56 \times 10^{-2} \; mol \; C_8H_{10}N_4O_2$$

Solution 17: What is the mass of 1.94×10^{22} lead atoms?

1 mol Pb = 6.022×10^{23} atoms Pb (Avogadro's Number)
1 mol Pb = 207.2 g Pb (molar mass)

$$1.94 \times 10^{22} \; \cancel{atoms\ Pb} \times \frac{1 \; \cancel{mol\ Pb}}{6.022 \times 10^{23} \; \cancel{atoms\ Pb}} \times \frac{207.2 \; g \; \text{Pb}}{1 \; \cancel{mol\ Pb}} =$$
$$= \frac{1.94 \times 10^{22} \times 207.2 \; g \; \text{Pb}}{6.022 \times 10^{23}}$$
$$\approx 6.61 \; g \; \text{Pb}$$

Solution 18: How many water molecules are in a 25.33 g ice cube?

1 mol H_2O = 6.022×10^{23} molecules H_2O (Avogadro's Number)

$$\text{molar mass:} \quad \begin{array}{l} \quad\quad H_2O \\ H_2 = 1.008\times 2 = 2.016 \\ O \quad\quad\quad\quad\;\; = 16.00 \\ \quad\quad H_2O \approx 18.02\ g/mol \end{array}$$

$$25.33\ \cancel{g\ H_2O}\times\frac{1\ \cancel{mol\ H_2O}}{18.02\ \cancel{g\ H_2O}}\times\frac{6.022\times10^{23}\ molecules\ H_2O}{1\ \cancel{mol\ H_2O}}=$$

$$=\frac{25.33\times6.022\times10^{23}\ molecules\ H_2O}{18.02}$$

$$\approx 8.465\times10^{23}\ molecules\ H_2O$$

Solution 19: What is the mass of 2.4×10^{23} acetone molecules? The molecular formula of acetone is C_3H_6O.

1 mol C_3H_6O = 6.022×10^{23} molecules C_3H_6O (Avogadro's Number)

$$\text{molar mass:} \quad \begin{array}{l} \quad\quad C_3H_6O \\ C_3 = 12.01\times 3 = 36.03 \\ H_6 = 1.008\times 6 = 6.048 \\ O \quad\quad\quad\quad\;\; = 16.00 \\ \quad\quad C_3H_6O \approx 58.08\ g/mol \end{array}$$

$$2.4\times10^{23}\ \cancel{molcules\ C_3H_6O}\times\frac{1\ \cancel{mol\ C_3H_6O}}{6.022\times10^{23}\ \cancel{molcules\ C_3H_6O}}\times\frac{58.08\ g\ C_3H_6O}{1\ \cancel{mol\ C_3H_6O}}=$$

$$=\frac{2.4\times10^{23}\times58.08\ g\ C_3H_6O}{6.022\times10^{23}}$$

$$\approx 23\ g\ C_3H_6O$$

Solution 20: Acetaminophen is a pain reliever and fever reducer; used as the active ingredient in Tylenol and many over-the-counter cold medicines. Analysis shows that it is 63.54% carbon, 6.00% hydrogen, 9.27% nitrogen, and 21.16% oxygen by mass. What is the empirical formula of acetaminophen?

step 1: assume 100 g sample and convert elements to moles - use the molar mass:

$$63.54\ g\ \text{C} \times \frac{1\ mol\ \text{C}}{12.01\ g\ \text{C}} = 5.291\ mol\ \text{C}$$
$$6.00\ g\ \text{H} \times \frac{1\ mol\ \text{H}}{1.008\ g\ \text{H}} = 5.95\ mol\ \text{H}$$
$$9.27\ g\ \text{N} \times \frac{1\ mol\ \text{N}}{14.01\ g\ \text{N}} = 0.662\ mol\ \text{N}$$
$$21.16\ g\ \text{O} \times \frac{1\ mol\ \text{O}}{16.00\ g\ \text{O}} = 1.322\ mol\ \text{O}$$

step 2: divide all the moles values by the smallest mole value to get whole numbers:

$$5.291\ mol\ \text{C} \div 0.662\ mol \approx 8\ \text{C}$$
$$5.95\ mol\ \text{H} \div 0.662\ mol \approx 9\ \text{H}$$
$$0.662\ mol\ \text{N} \div 0.662\ mol \approx 1\ \text{N}$$
$$1.322\ mol\ \text{O} \div 0.662\ mol \approx 2\ \text{O}$$

the empirical formula of acetaminophen is $C_8H_9NO_2$

Solution 21: Caffeine is a mild stimulant that naturally occurs in coffee and tea, and is added to energy drinks and many sodas. It contains 49.48% carbon, 5.15% hydrogen, 28.87% nitrogen, and 16.49% oxygen by mass and has a molar mass of 194.2 g/mol. What are the empirical and molecular formulae of caffeine?

To find empirical formula:
step 1: assume 100 g sample and convert elements to moles:

$$49.48\ g\ \text{C} \times \frac{1\ mol\ \text{C}}{12.01\ g\ \text{C}} = 4.120\ mol\ \text{C}$$

$$5.15\ g\ \text{H} \times \frac{1\ mol\ \text{H}}{1.008\ g\ \text{H}} = 5.11\ mol\ \text{H}$$

$$28.87\ g\ \text{N} \times \frac{1\ mol\ \text{N}}{14.01\ g\ \text{N}} = 2.061\ mol\ \text{N}$$

$$16.49\ g\ \text{O} \times \frac{1\ mol\ \text{O}}{16.00\ g\ \text{O}} = 1.030\ mol\ \text{O}$$

step 2: divide all the moles values by the smallest mole value to get whole numbers:

$$4.120\ mol\ \text{C} \div 1.030\ mol \approx 4\ \text{C}$$

$$5.11\ mol\ \text{H} \div 1.030\ mol \approx 5\ \text{H}$$

$$2.061\ mol\ \text{N} \div 1.030\ mol \approx 2\ \text{N}$$

$$1.030\ mol\ \text{O} \div 1.030\ mol \approx 1\ \text{O}$$

the empirical formula of caffeine is $C_4H_5N_2O$

To find molecular formula:

step 1: use the empirical formula to find empirical mass - ignore decimal places:

$$C_4H_5N_2O$$

$$C_4 = 12 \times 4 = 48$$

$$H_5 = 1 \times 5 = 5$$

$$N_2 = 14 \times 2 = 28$$

$$O = 16$$

$$C_4H_5N_2O = 97\ g/mol$$

step 2: divide the given molar mass by the empirical formula, to get a whole number to multiply the empirical formula:

$$\frac{molar\ mass}{empirical\ mass} = \frac{194.2}{94} \approx 2$$

the molecular formula of caffeine is $C_8H_{10}N_4O_2$

Solution 22: The primary component of gasoline is isooctane. The balanced equation for the combustion of isooctane is:

$$2\ C_8H_{18\ (l)} + 25\ O_{2\ (g)} \longrightarrow 16\ CO_{2\ (g)} + 18\ H_2O_{(l)}$$

What mass of carbon dioxide is released by the complete combustion of 1 gallon (2800 g) of gasoline?

given is 2800 g C_8H_{18} with molar mass of 8 (12.01) + 18 (1.008) = 114.2 g/mol
unknown is CO_2 with molar mass of 12.01 + 2 (16.00) = 44.01 g/mol
mole ratio is 2 mol C_8H_{18} = 16 mol CO_2

step 1: convert given to moles - use molar mass

$$2800\ g\ \mathrm{C_8H_{18}} \times \frac{1\ mol\ \mathrm{C_8H_{18}}}{114.2\ g\ \mathrm{C_8H_{18}}} = 24.52\ mol\ \mathrm{C_8H_{18}}$$

step 2: convert given to unknown - use mole ratio

$$24.52\ mol\ \mathrm{C_8H_{18}} \times \frac{16\ mol\ \mathrm{CO_2}}{2\ mol\ \mathrm{C_8H_{18)}}} = 196.4\ mol\ \mathrm{CO_2}$$

step 3: convert unknown from moles - use molar mass

$$196.4\ mol\ \mathrm{CO_2} \times \frac{44.01\ g\ \mathrm{CO_2}}{1\ mol\ \mathrm{CO_2}} = 8632\ g\ \mathrm{CO_2} \approx 8600\ g\ \mathrm{CO_2}$$

"Notice that the mass is very large. There are 250 million cars and trucks in the United States alone. The total mass of carbon dioxide produced by human activity is measured in Gigatons (billions of tons) per year. This amount is so huge that it is changing the whole Earth; increasing the natural atmospheric CO2 content by 45% and causing global warming. Many scientists are frightened that we are already past the point of no return: that no matter what we do now, people will die - are already dying."

Since this a long process, we usually don't calculate the three steps separately. We set up three continuous steps first, before calculating everything at once. "Take the express, not the local."

$$x\ g \text{ given} \times \frac{moles \text{ given}}{g \text{ given}} \times \frac{moles \text{ unknown}}{moles \text{ given}} \times \frac{g \text{ unknown}}{moles \text{ unknown}} = y\ g \text{ unknown}$$

$$2800\ g\ \mathrm{C_8H_{18}} \times \frac{1\ mol\ \mathrm{C_8H_{18}}}{114.2\ g\ \mathrm{C_8H_{18}}} \times \frac{16\ mol\ \mathrm{CO_2}}{2\ mol\ \mathrm{C_8H_{18}}} \times \frac{44.01\ g\ \mathrm{CO_2}}{1\ mol\ \mathrm{CO_2}} \approx 8600\ g\ \mathrm{CO_2}$$

Solution 23: Ordinary limestone (calcium carbonate) can be dissolved in a nitric acid solution according to the following equation:

$$\mathrm{CaCO_3}_{\ (s)} + 2\ \mathrm{HNO_3}_{\ (aq)} \longrightarrow \mathrm{Ca(NO_3)_2}_{\ (aq)} + \mathrm{CO_2}_{\ (g)} + \mathrm{H_2O}_{(l)}$$

If the solution contains 100. g of nitric acid, what maximum mass of limestone could be dissolved?

given is 100. g HNO_3 with molar mass of 1.008 + 14.01 + 3 (16.00) = 63.02 g/mol
unknown is $CaCO_3$ with molar mass of 40.08 + 12.01 + 3 (16.00) = 100.1 g/mol
mole ratio is 2 mol HNO_3 = 1 mol $CaCO_3$

$$100.\, g\, \mathrm{HNO_3} \times \frac{1\, mol\, \mathrm{HNO_3}}{63.02\, g\, \mathrm{HNO_3}} \times \frac{1\, mol\, \mathrm{CaCO_3}}{2\, mol\, \mathrm{HNO_3}} \times \frac{100.1\, g\, \mathrm{CaCO_3}}{1\, mol\, \mathrm{CaCO_3}} \approx 79.4\, g\, \mathrm{CaCO_3}$$

Solution 24: The most important industrial element is iron. Over a billion tons of iron is refined annually worldwide, to make steel and build everything from washing machines to skyscrapers. Additional hundreds of millions of tons of iron is recycled. However, pure iron is virtually nonexistent in nature. Iron must be refined from iron ores. A high quality iron ore is the reddish-brown mineral called hematite, Fe_2O_3. Hematite can be smelted (heated with coke, a form of almost pure carbon made from coal) at ~1900 °C to produce almost pure iron. The process' overall equation is:

$$2\ \mathrm{Fe_2O_3}_{\,(s)} \ +\ 3\ \mathrm{C}_{(s)} \xrightarrow{\Delta} 4\ \mathrm{Fe}_{(l)} \ +\ 3\ \mathrm{CO_2}_{\,(g)}$$

If smelting 57.8 tons of hematite produces 37.3 tons of iron, what is the percent yield of iron?

given is 57.8 tons Fe_2O_3 with molar mass of 2 (55.85) + 3 (16.00) = 159.7 g/mol
unknown is tons Fe with molar mass of 55.85 g/mol, and actual yield = 37.3 tons
(since both masses are in tons, converting to tons to grams is not necessary)
mole ratio is 2 mol Fe_2O_3 = 4 mol Fe
actual yield = 37.3 tons Fe

$$57.8\, tons\, \mathrm{Fe_2O_3} \times \frac{1\, mol\, \mathrm{Fe_2O_3}}{159.7\, g\, \mathrm{Fe_2O_3}} \times \frac{4\, mol\, \mathrm{Fe}}{2\, mol\, \mathrm{Fe_2O_3}} \times \frac{55.85\, g\, \mathrm{Fe}}{1\, mol\, \mathrm{Fe}} \approx 40.4\, tons\, \mathrm{Fe}$$

$$\begin{aligned} \%\ yield &= \frac{actual\ yield}{theoretical\ yield} \times 100 \\ &= \frac{37.3\ tons\ \mathrm{Fe}}{40.4\ tons\ \mathrm{Fe}} \times 100 \\ &= 92.3\,\%\,yield\ \mathrm{Fe} \end{aligned}$$

Solution 25: Household ammonia (NH_3) and bleach ($NaOCl$) must never be mixed, because they will react and produce hydrazine (N_2H_4), a toxic gas. The balanced equation is:

$$2\ NH_{3\ (aq)}\ +\ NaOCl_{(aq)}\ \longrightarrow\ N_2H_{4\ (g)|}\ +\ NaCl_{aq}\ +\ H_2O_{(l)}$$

Suppose you ignore the warning labels, and combine 25.0 g NH_3 with 25.0 g NaOCl. Which reactant is the limiting reagent? What mass of N_2H_4 would be produced?

givens are 25.0 g NH_3 with molar mass of 14.01 + 3(1.008) ≈ 17.03 g/mol
25.0 g NaOCl with molar mass of 22.99 + 16.00 + 35.45 = 74.44 g/mol
N_2H_4 molar mass of 2(14.01) + 4(1.008) = 32.05 g/mol
and mole ratio is 2 mol NH_3 = 1 mol NaOCl = 1 mol N_2H_4

unknowns are limiting reagent and grams N_2H_4.

step 1: convert both givens to moles - use molar mass

$$25.0\ g\ \mathrm{NH_3} \times \frac{1\ mol\ \mathrm{NH_3}}{17.03\ g\ \mathrm{NH_3}} = 1.468\ mol\ \mathrm{NH_3}$$

$$25.0\ g\ \mathrm{NaOCl} \times \frac{1\ mol\ \mathrm{NaOCl}}{74.44\ g\ \mathrm{NaOCl}} = 0.3358\ mol\ \mathrm{NaOCl}$$

step 1A: identify limiting/excess reagent - divide by mole count

$$1.468\ mol\ \mathrm{NH_3} \div 2\ mol = 0.734$$

$$0.3358\ mol\ \mathrm{NaOCl} \div 1\ mol = 0.3358$$

since 0.3358 is less than 0.734, the 0.3358 mol NaOCl is the limiting reagent
and the 1.468 mol NH_3 is the excess reagent.

step 2: convert limiting to unknown - use mole ratio

$$0.3358\ mol\ \mathrm{NaOCl} \times \frac{1\ mol\ \mathrm{N_2H_4}}{1\ mol\ \mathrm{NaOCl}} = 0.3358\ mol\ \mathrm{N_2H_4}$$

step 3: convert unknown from moles - use molar mass

$$0.3358\ mol\ \mathrm{N_2H_4} \times \frac{32.05\ g\ \mathrm{N_2H_4}}{1\ mol\ \mathrm{N_2H_4}} \approx 10.8\ g\ \mathrm{N_2H_4}$$

Solution 26: Lithium is in great demand today for the lithium-ion batteries that power our smartphones and electric cars. Much lithium is pumped up from underground salty water aquifers, and the potassium/sodium/lithium chlorides are concentrated by solar evaporation. The lithium is then reacted with sodium carbonate and precipitated as lithium carbonate, for further processing:

$$2\,LiCl_{(aq)} + Na_2CO_{3\,(aq)} \longrightarrow Li_2CO_{3\,(s)} + 2\,NaCl_{(aq)}$$

If 1.94×10³ g LiCl reacts with 4.91×10³ g Na_2CO_3, which reactant is the limiting reagent? What mass of Li_2CO_3 would be produced?

givens are 1.94×10³ g LiCl with molar mass of 6.941 + 35.45 ≈ 42.39 g/mol,
4.91×10³ g Na_2CO_3 with molar mass of 2(22.99) + 12.01 + 3(16.00) = 95.99 g/mol
Li_2CO_3 molar mass of 2(6.941) + 12.01 + 3(16.00) ≈ 73.95 g/mol
and mole ratio is 2 mol LiCl = 1 mol Na_2CO_3 = 1 mol Li_2CO_3

unknowns are limiting reagent and grams Li_2CO_3.

step 1: convert both givens to moles. step 1A: identify limiting/excess reagent

$$1.94 \times 10^3\ g\ \text{LiCl} \times \frac{1\ mol\ \text{LiCl}}{42.39\ g\ \text{LiCl}} \approx 45.8\ mol\ \text{LiCl} \quad \div 2\ mol = 22.9$$

$$3.85 \times 10^3\ g\ \text{Na}_2\text{CO}_3 \times \frac{1\ mol\ \text{Na}_2\text{CO}_3}{95.99\ g\ \text{Na}_2\text{CO}_3} \approx 40.1\ mol\ \text{Na}_2\text{CO}_3 \quad \div 2\ mol = 40.1$$

since 22.9 is less than 40.1, the 45.8 mol LiCl is the limiting reagent
and the 40.1 mol Na_2CO_3 is the excess reagent.

step 2: convert limiting to unknown. step 3: convert unknown from moles

$$45.8\ mol\ \text{LiCl} \times \frac{1\ mol\ \text{Li}_2\text{CO}_3}{2\ mol\ \text{LiCl}} \times \frac{73.95\ g\ \text{Li}_2\text{CO}_3}{1\ mol\ \text{Li}_2\text{CO}_3} \approx 1.69 \times 10^3\ g\ \text{Li}_2\text{CO}_3$$

Solution 27: Millions of tons of hydrochloric acid are used every year for "metal pickling" - removing any rust or corrosion from metal surfaces - before final finishing. The reaction with iron(III) oxide is:

$$Fe_2O_{3\,(s)} + 6\,HCl_{(aq)} \longrightarrow 2\,FeCl_{3\,(aq)} + 3\,H_2O_{(l)}$$

If a steel sheet with 5.29 g Fe_2O_3 rust is pickled with 2.45 g HCl, would all the rust be removed? What mass of $FeCl_3$ would be produced? If the rust is the excess reagent, what mass of Fe_2O_3 would remain?

givens are 5.29 g Fe_2O_3 with molar mass of 2(55.85) + 3(16.00) ≈ 159.7 g/mol,
2.45 g HCl with molar mass of 1.008 + 35.45 ≈ 36.46 g/mol
$FeCl_3$ molar mass of 55.85 + 3(35.45) ≈ 162.2 g/mol
and mole ratio is 1 mol Fe_2O_3 = 6 mol HCl = 2 mol $FeCl_3$

unknowns are whether Fe_2O_3 is limiting, grams $FeCl_3$, produced, and Fe_2O_3 leftover (if any)

step 1: convert both givens to moles. step 1A: identify limiting/excess reagent

$$5.29\ g\ Fe_2O_3 \times \frac{1\ mol\ Fe_2O_3}{159.7\ g\ Fe_2O_3} \approx 0.0331\ mol\ Fe_2O_3 \quad \div 1\ mol = 0.0331$$

$$2.45 \times 10^3\ g\ HCl \times \frac{1\ mol\ HCl}{36.46\ g\ HCl} \approx 0.0671\ mol\ HCl \quad \div 6\ mol = 0.0112$$

since 0.0112 is less than 0.0331, the 0.0671 mol HCl is the limiting reagent and the 0.0331 mol Fe_2O_3 is the excess reagent. Therefore, some of the rust will NOT be stripped.

step 2: convert limiting to unknown. step 3: convert unknown from moles

$$0.0671\ mol\ HCl \times \frac{2\ mol\ FeCl_3}{6\ mol\ HCl} \times \frac{162.2\ g\ FeCl_3}{1\ mol\ FeCl_3} \approx 3.63\ g\ FeCl_3$$

step 2: convert limiting to excess. step 3: convert excess from moles

$$0.0671\ mol\ HCl \times \frac{1\ mol\ Fe_2O_3}{6\ mol\ HCl} \times \frac{159.7\ g\ Fe_2O_3}{1\ mol\ Fe_2O_3} \approx 1.79\ g\ Fe_2O_3 \text{ used up}$$

5.29 g Fe_2O_3 given - 1.79 g Fe_2O_3 used up = 3.50 g Fe_2O_3 left over

Solution 28: Benzene is a carcinogen that contaminates many old industrial sites, such as parts of the Brooklyn Navy Yard, because it was commonly used as a solvent, before its danger was understood. It is a hydrocarbon, containing only the elements carbon and hydrogen. If complete combustion of a 0.799 g benzene sample produces 2.701 g carbon dioxide and 0.553 g water, and its molar mass is 78.1 g/mol, what are the empirical and molecular formulae of benzene?

Part 1: from combustion to mass composition:

The combustion reaction equation must like this, although it cannot be balanced:

$$C_xH_y + O_2 \longrightarrow CO_2 + H_2O$$

given is 2.701 g CO_2 with molar mass of 12.01 + 2 (16.00) = 44.01 g/mol,
0.553 g H_2O with molar mass of 2 (1.008) + 16.00 = 18.02 g/mol
and a 0.799 g sample.

$$2.701\ g\ CO_2 \times \frac{1\ mol\ CO_2}{44.01\ g\ CO_2} \times \frac{1\ mol\ C}{1\ mol\ CO_2} \times \frac{12.01\ g\ C}{1\ mol\ C} \approx 0.7371\ g\ C$$

$$0.553\,g\,H_2O \times \frac{1\,mol\,H_2O}{18.02\,g\,H_2O} \times \frac{2\,mol\,H}{1\,mol\,H_2O} \times \frac{1.008\,g\,H}{1\,mol\,H} \approx 0.0619\,g\,H$$

Part 2: from mass composition to empirical formula:

step 1: convert all elements to moles

$$0.7371\,g\,C \times \frac{1\,mol\,C}{12.01\,g\,C} = 0.06137\,mol\,C$$
$$0.0619\,g\,H \times \frac{1\,mol\,H}{1.008\,g\,H} = 0.0614\,mol\,H$$

step 2: divide by smallest moles; if result is not all whole numbers, multiply by fraction denominator:

$$0.06137\,mol\,C \div 0.0614\,mol \approx 1\ C$$
$$0.0614\,mol\,H \div 0.0614\,mol \approx 1\ H$$

the empirical formula of benzene is CH

Part 3: from empirical formula to molecular formula:

step 1: use the empirical formula to find empirical mass - ignore decimal places:

CH
C = 12
H = 1
CH = 13 g/mol

step 2: divide the given molar mass by the empirical formula, to get a whole number to multiply the empirical formula:

$$\frac{molar\ mass}{empirical\ mass} = \frac{78.1}{13} \approx 6$$

the molecular formula of benzene is C_6H_6

Solution 29: Para-cresol, a substance used as a disinfectant, is a molecule that contains the elements carbon, hydrogen, and oxygen. Complete combustion of a 0.345 g sample of p-cresol produced 0.983 g carbon dioxide and 0.230 g water. Determine the empirical formula for p-cresol.

Solution:

Part 1: from combustion to mass composition:

The combustion reaction equation must like this, although it cannot be balanced:

$$C_xH_yO_z \ + \ O_2 \ \longrightarrow \ CO_2 \ + \ H_2O$$

given is 0.983 g CO_2 with molar mass of 12.01 + 2 (16.00) = 44.01 g/mol,
0.230 g H_2O with molar mass of 2 (1.008) + 16.00 = 18.02 g/mol
and a 0.345 g sample.

$$0.983\ g\ CO_2 \times \frac{1\ mol\ CO_2}{44.01\ g\ CO_2} \times \frac{1\ mol\ C}{1\ mol\ CO_2} \times \frac{12.01\ g\ C}{1\ mol\ C} \approx 0.2683\ g\ C$$

$$0.230\ g\ H_2O \times \frac{1\ mol\ H_2O}{18.02\ g\ H_2O} \times \frac{2\ mol\ H}{1\ mol\ H_2O} \times \frac{1.008\ g\ H}{1\ mol\ H} \approx 0.0257\ g\ H$$

$\therefore$ 0.345 g sample - 0.2683 g C - 0.0257 g H = 0.051 g O

Part 2: from mass composition to empirical formula:

step 1: convert all elements to moles

$$0.2683\ g\ C \times \frac{1\ mol\ C}{12.01\ g\ C} = 0.02234\ mol\ C$$

$$0.0257\ g\ H \times \frac{1\ mol\ H}{1.008\ g\ H} = 0.02550\ mol\ H$$

$$0.051\ g\ O \times \frac{1\ mol\ O}{16.00\ g\ O} = 0.00319\ mol\ O$$

step 2: divide by smallest moles:

$$\begin{aligned} 0.02234\ mol\ C \div 0.00319\ mol &= 7\ C \\ 0.02550\ mol\ H \div 0.00319\ mol &= 8\ H \\ 0.00319\ mol\ O \div 0.00319\ mol &= 1\ O \end{aligned}$$

the empirical formula of para-cresol is C_7H_8O