Chem With Com

Stoichiometry

- Chapter 7.3 (Reaction Stoichiometry)
- Chapter 7.4 (Reaction Yields)
- Chapter 7.5 (Quantitative Chemical Analysis)

Adapted From: Paul Flowers, Edward J. Neth, William R. Robinson, PhD, Klaus Theopold, Richard Langley; Chemistry: Atoms First 2e; OpenStax; Feb 14, 2019; Houston Texas; https://openstax.org/books/chemistry-atoms-first-2e/pages/1-introduction

Stoichiometry Basics

- Chapter 7.3 (Reaction Stoichiometry)

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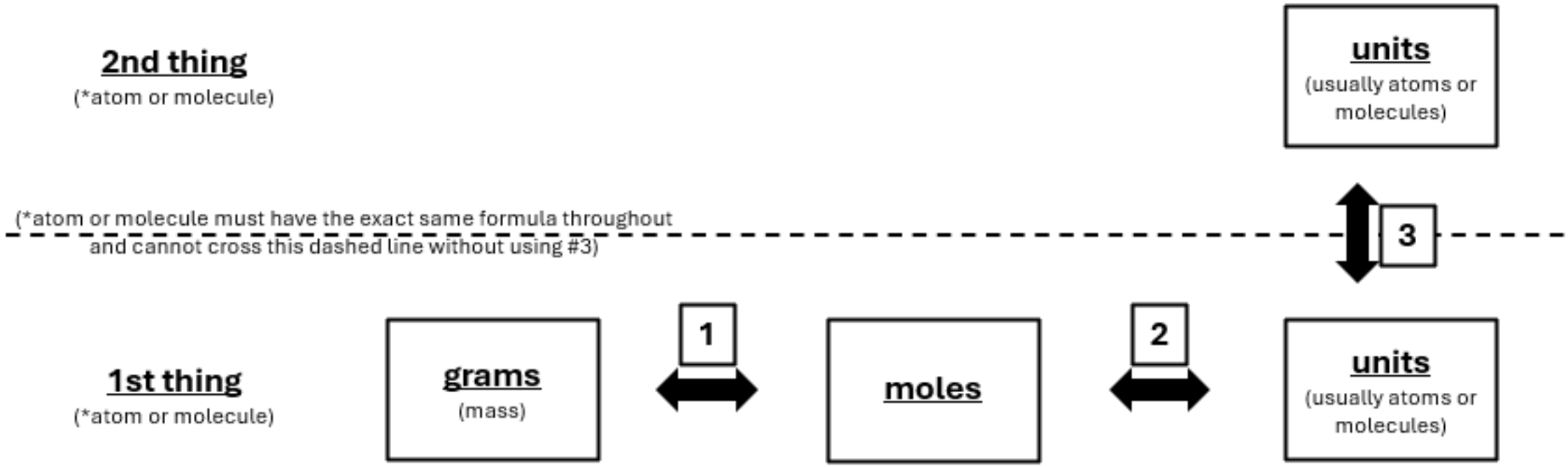
Review
Topic 6: Measurements, Prefixes, and Dimensional Analysis
Part 4 of 4: Dimensional Analysis (grams to moles to units)



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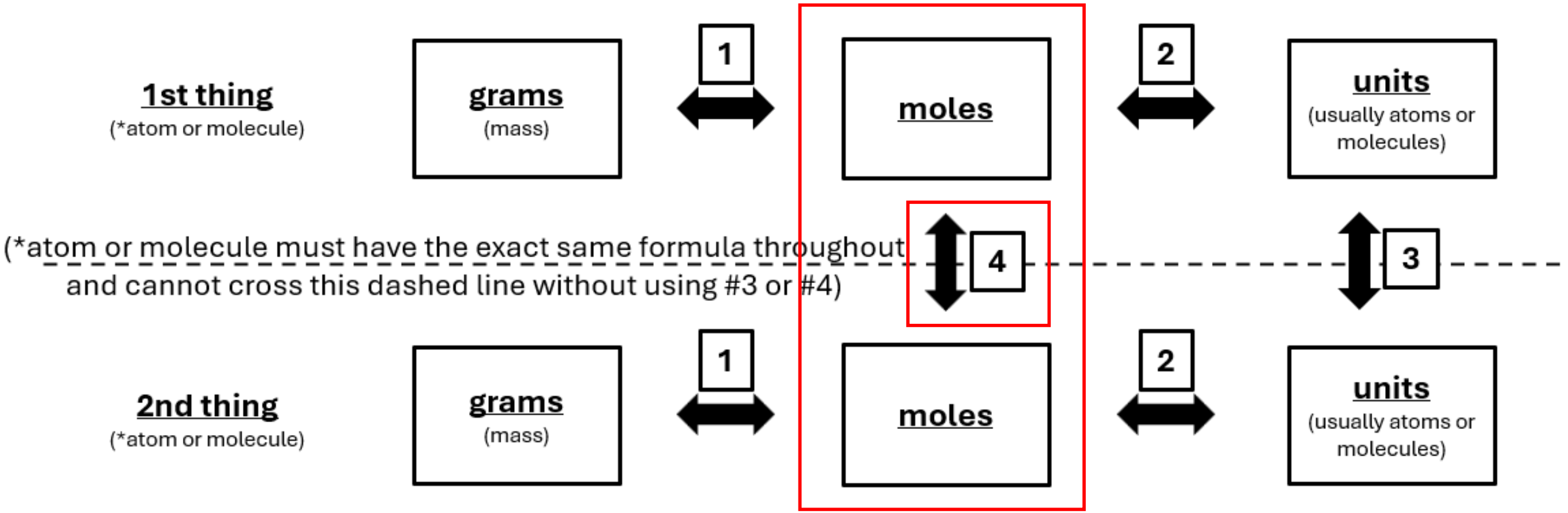
2. 6.022×10^{23} units = 1 mol
3. for going from atoms within molecules or molecules to atoms use the **mole ratio of the atoms within the molecule** (i.e. 2 atoms F = 1 molecule BaF_2)

Stoichiometry expands on this using the mole ratio.



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A recipe lets you know how much you need of things, and how much you can make of something

2 Bread + 1 Cheese → 1 Sandwich

Ratio

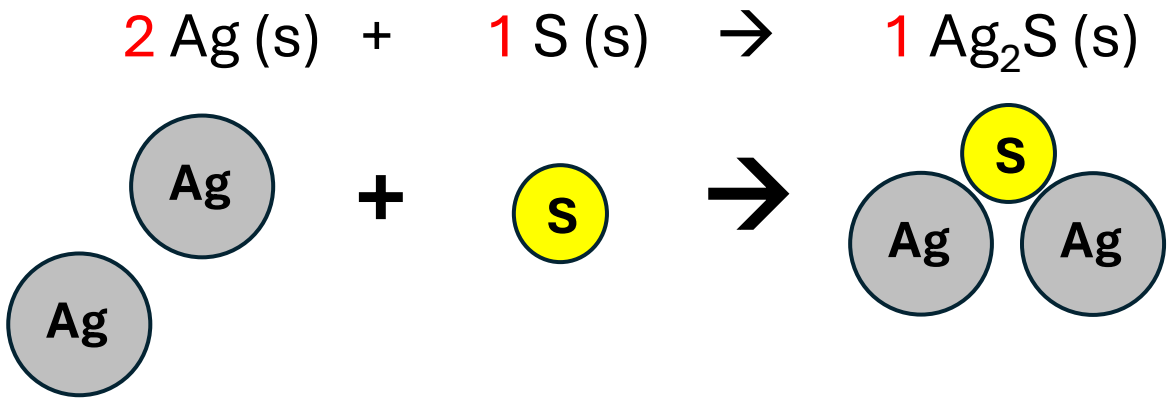
2 bread : 1 cheese

1 cheese : 1 sandwich

2 bread : 1 sandwich

- If we have 10 bread, how many cheese do we need?
- If we have 20 sandwiches, how many pieces of bread do we have?
- If we have 3 pieces of cheese, how many sandwiches can we make if we had unlimited bread?

A balanced equation lets you know how much you need of things, and how much you can make of something



Mole Ratio

2 Ag : 1 S

1 S : 1 Ag_2S

2 Ag : 1 Ag_2S

- If we have 10 silver, how many sulfur do we need?
- If we have 20 silver sulfides, how many silver to we have?
- If we have 3 sulfur, how many silver sulfides can we make if we had unlimited silver?

The mole ratio works for food

1 pack eggs + 3 packs of flour → 2 boxes of noodles

1 pack eggs to 3 packs of flour

1 pack eggs to 2 boxes of noodles

3 packs of flour to 2 boxes of noodles

Ratios

3 packs flour : 2 boxes noodles

3 dozen packs flour : 2 dozen boxes noodles

3 hundred packs flour : 2 hundred boxes noodles

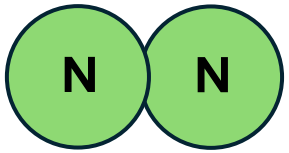
3 moles of packs of flour : 2 moles of boxes of noodles

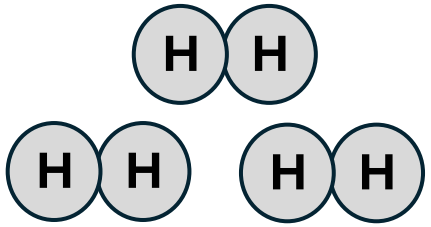
$3 \times (6.022 \times 10^{23})$ packs of flour : $2 \times (6.022 \times 10^{23})$ boxes of noodles

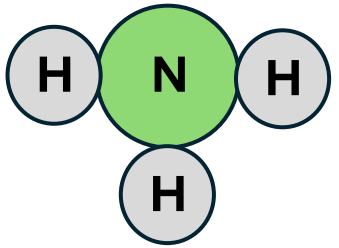
The mole ratio works for chemical equations.

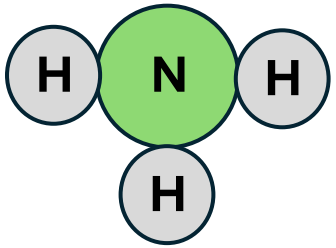
1 pack eggs + 3 packs of flour → 2 boxes of noodles

1 $N_2(g)$ + 3 $H_2(g)$ → 2 $NH_3(g)$









1 N_2 to 3 H_2

1 N_2 to 2 NH_3

3 H_2 to 2 NH_3

Ratios

3 H_2 : 2 NH_3

3 dozen H_2 : 2 dozen NH_3

3 hundred H_2 : 2 hundred NH_3

3 moles H_2 : 2 moles NH_3

3 x (6.022×10^{23}) H_2 : 2 x (6.022×10^{23}) NH_3

The mole ratio works for molecules as well.

Sandwich

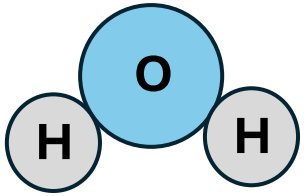
Mole Ratio

2 bread : 1 cheese

1 cheese : 1 sandwich

2 bread : 1 sandwich

Water



Mole Ratio

2 H : 1 O

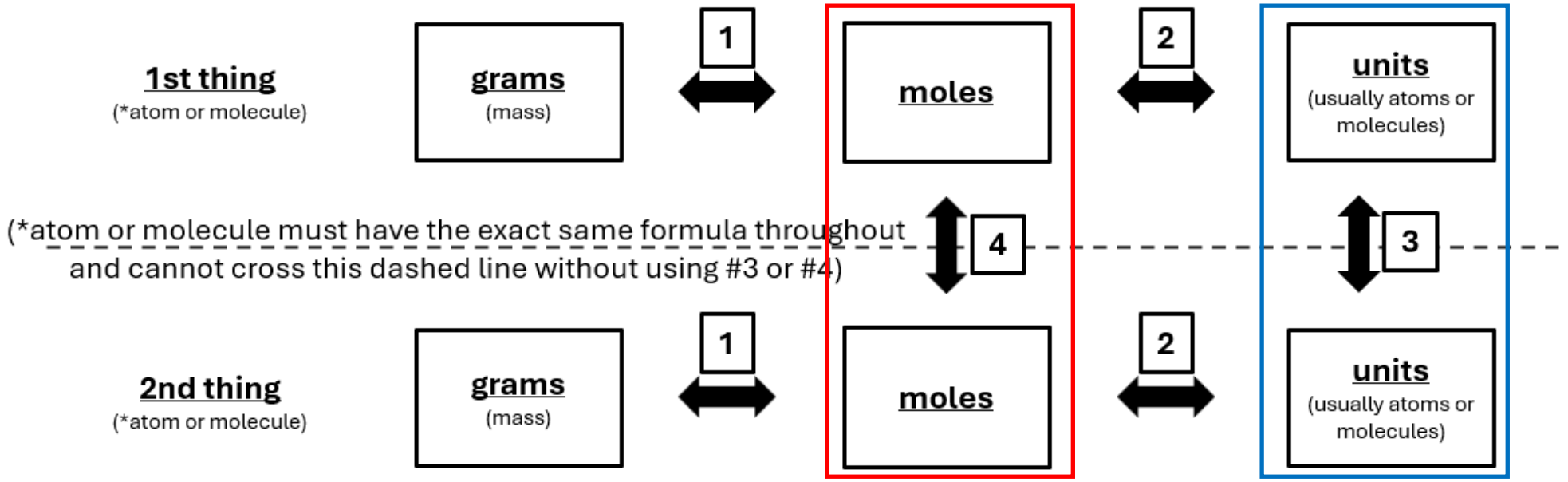
1 O : 1 H_2O

2 H : 1 H_2O

The mole ratio is used for calculations involving various products and reactants as well as atoms within molecules.

Mole ratio of atoms to molecules

Mole ratio within/between reactants and products



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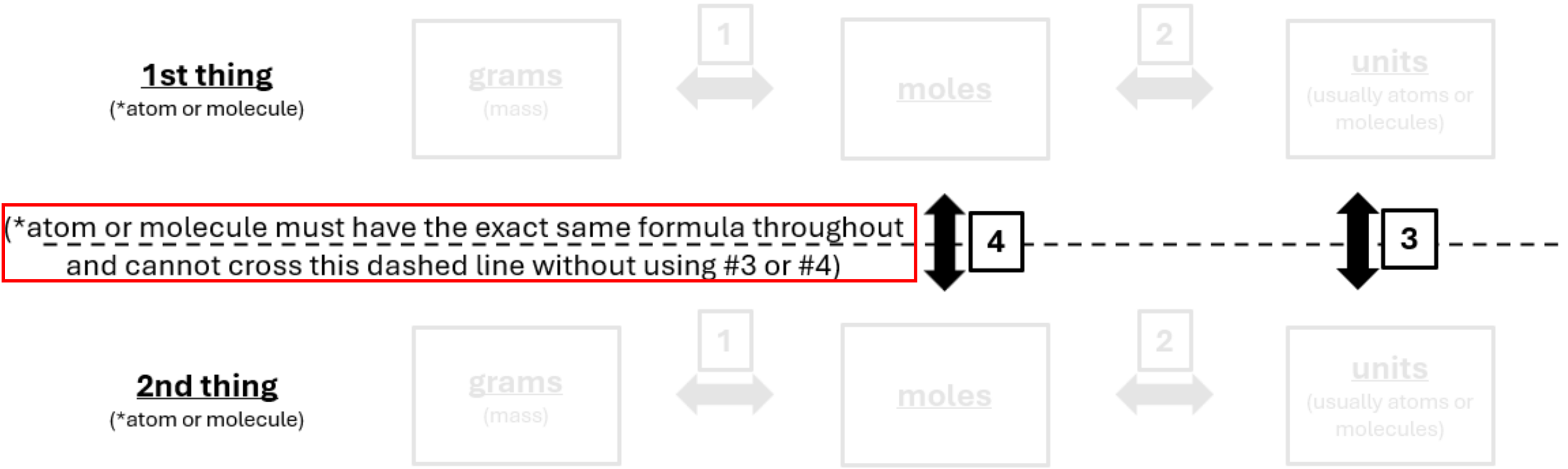
4. use the **mole ratio of the chemical equation** (i.e. 3 H_2 = 2 NH_3 in the chemical equation 1 N_2 + 3 H_2 → 2 NH_3)

Converting between moles of something to moles of something else requires the mole ratio



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EXAMPLE 7.8

Moles of Reactant Required in a Reaction

How many moles of I_2 are required to react with 0.429 mol of Al according to the following equation (see Figure 7.10)?

$$2Al + 3I_2 \longrightarrow 2AlI_3$$

Multiply the value you are trying to convert by the mole ratio with the unit you are trying to cancel out on the bottom

$$0.429 \text{ mol } \cancel{Al} \times \frac{3 \text{ mol } I_2}{2 \text{ mol } \cancel{Al}} = 0.6435 \text{ mol } I_2$$

$2\ Al : 3\ I_2$ (mole ratio)

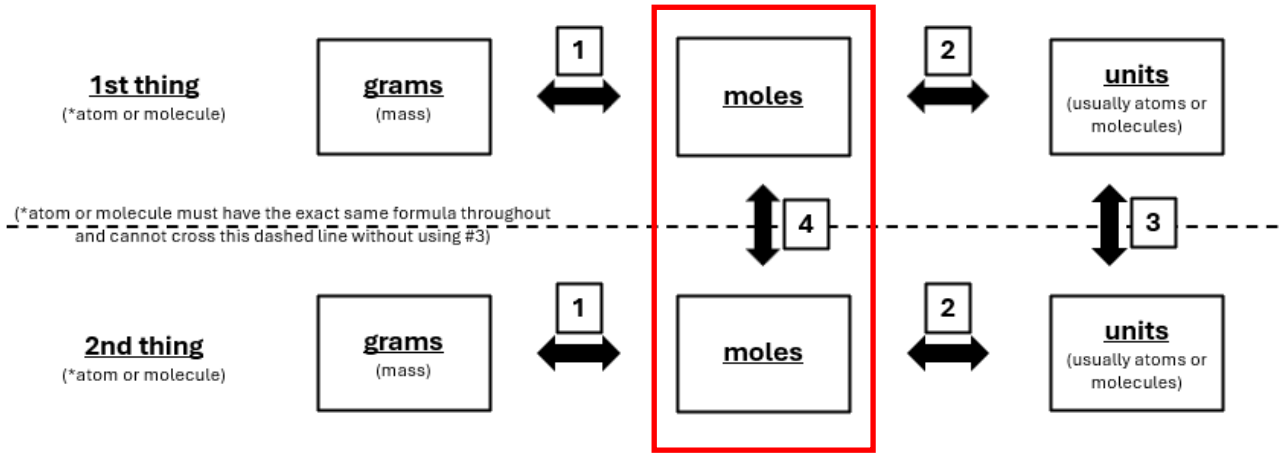
$4\ Al : 6\ I_2$ — 2 to 3 ratio

$20\ Al : 30\ I_2$ — 2 to 3 ratio

$1\ Al : 1.5\ I_2$ — 2 to 3 ratio

$0.5\ Al : 0.75\ I_2$ — 2 to 3 ratio

$0.429\ Al : 0.6435\ I_2$ — 2 to 3 ratio



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Practice Problems

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

1. How many mol of H_2 do we need to fully react 2 mol of N_2?
2. How many mol H_2 do you need to synthesize 12 mol NH_3?
3. If we have 1.5 mol N_2, how many mol NH_3 can we make if we had unlimited H_2?

Check Your Learning

How many moles of $Ca(OH)_2$ are required to react with 1.36 mol of H_3PO_4 to produce $Ca_3(PO_4)_2$ according to the equation $3Ca(OH)_2 + 2H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 6H_2O$?

Stoichiometry

- Chapter 7.3 (Reaction Stoichiometry)

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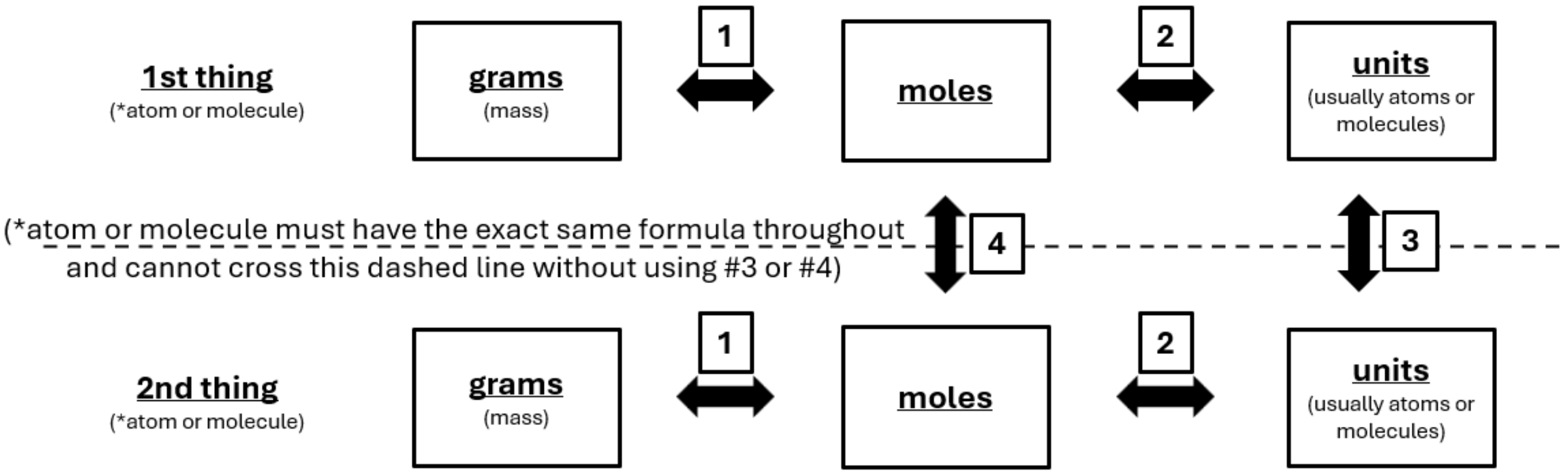
Stoichiometry Expands On This



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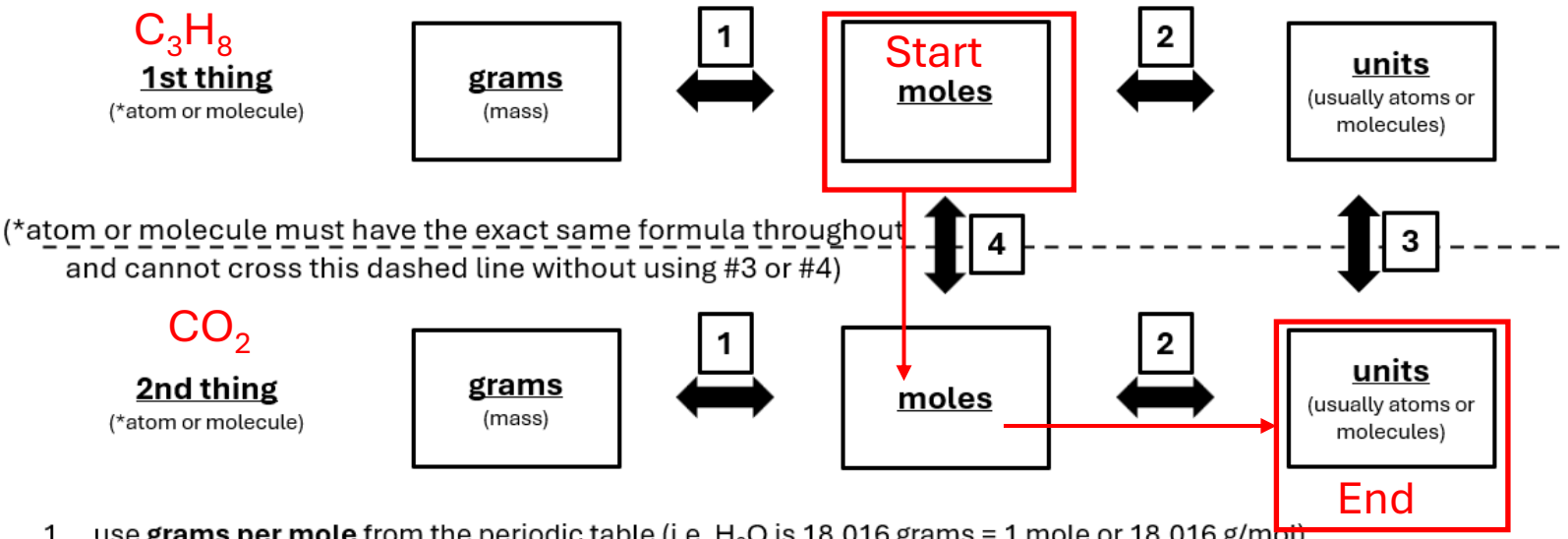
EXAMPLE 7.9

Number of Product Molecules Generated by a Reaction

How many carbon dioxide molecules are produced when 0.75 mol of propane is combusted according to this equation?

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$



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Step 1: Write one reactant or product on one side of the dotted line

Step 2: Write the other reactant or product on the other side of the dotted line

Step 3: Label your start and end points

Step 4: Move through the boxes only using the arrows and use the numbered conversion factors listed

$$0.75 \text{ mol } C_3H_8 \times \frac{3 \text{ mol } CO_2}{1 \text{ mol } C_3H_8} \times \frac{6.022 \times 10^{23} \text{ molecules } CO_2}{1 \text{ mol } CO_2} = 1.4 \times 10^{24} \text{ molecules } CO_2$$

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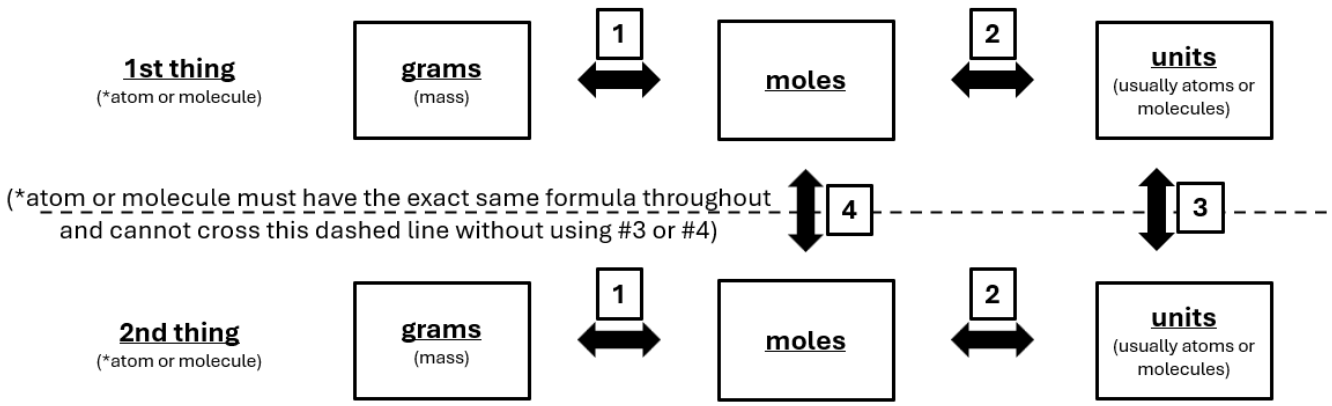

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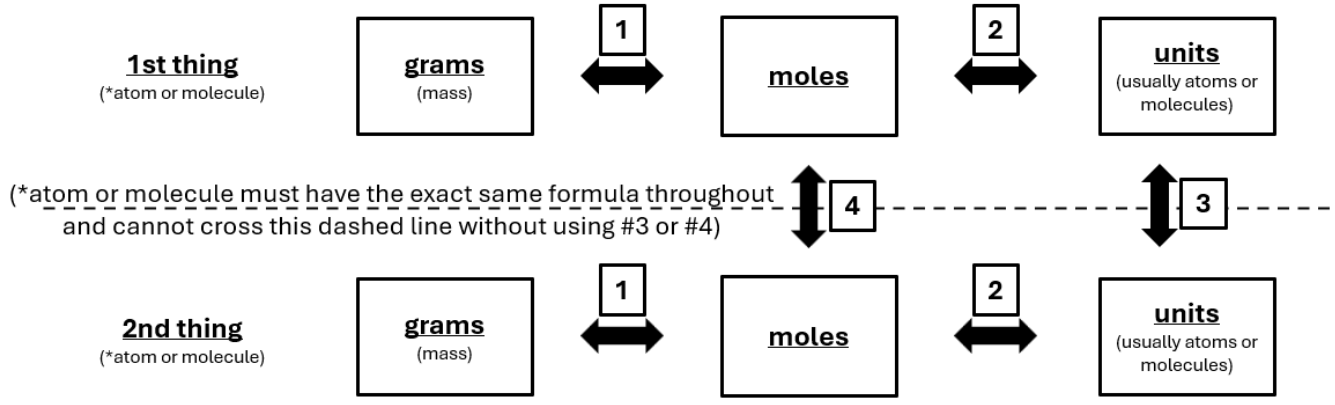
Check Your Learning

How many NH_3 molecules are produced by the reaction of 4.0 mol of $Ca(OH)_2$ according to the following equation:

$$(NH_4)_2SO_4 + Ca(OH)_2 \longrightarrow 2NH_3 + CaSO_4 + 2H_2O$$



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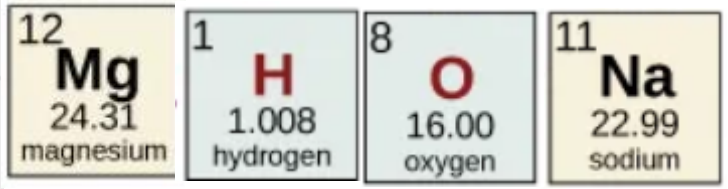
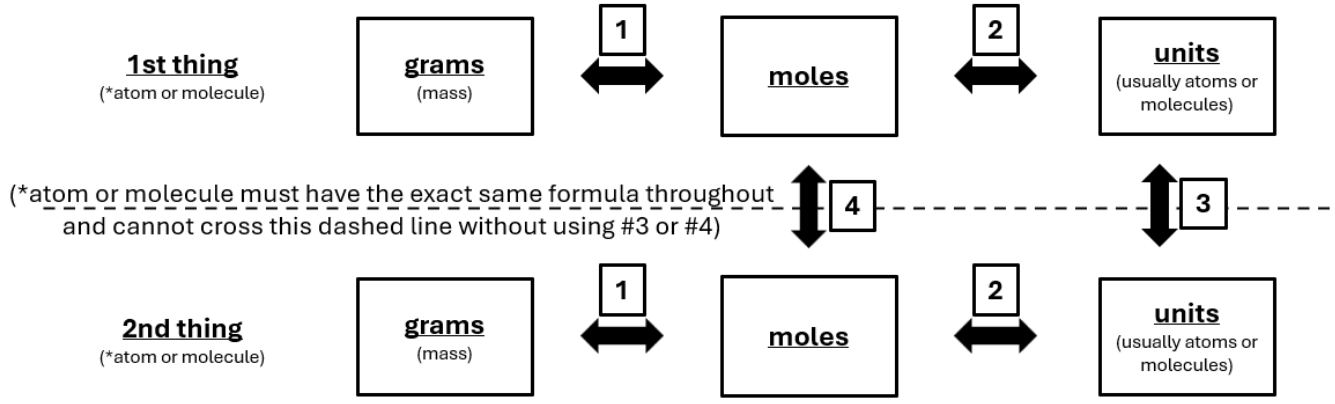
EXAMPLE 7.10

Relating Masses of Reactants and Products

What mass of sodium hydroxide, NaOH, would be required to produce 16 g of the antacid milk of magnesia [magnesium hydroxide, $Mg(OH)_2$] by the following reaction?

$$MgCl_2(aq) + 2NaOH(aq) \longrightarrow Mg(OH)_2(s) + 2NaCl(aq)$$





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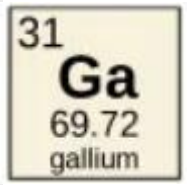
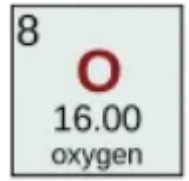
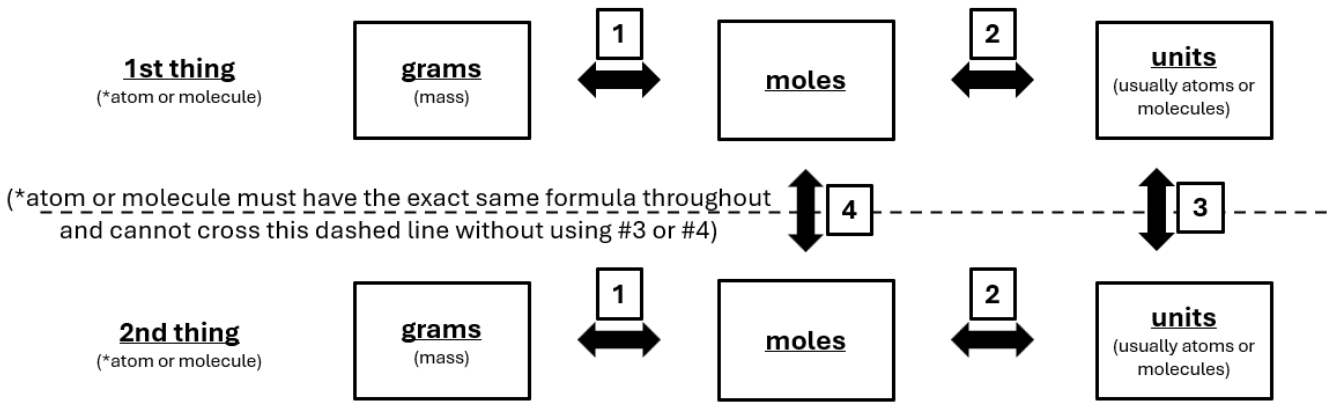
Check Your Learning

What mass of gallium oxide, Ga_2O_3, can be prepared from 29.0 g of gallium metal? The equation for the reaction is $4Ga + 3O_2 \longrightarrow 2Ga_2O_3$.







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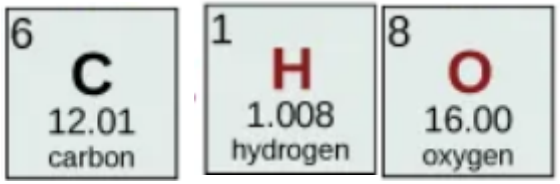
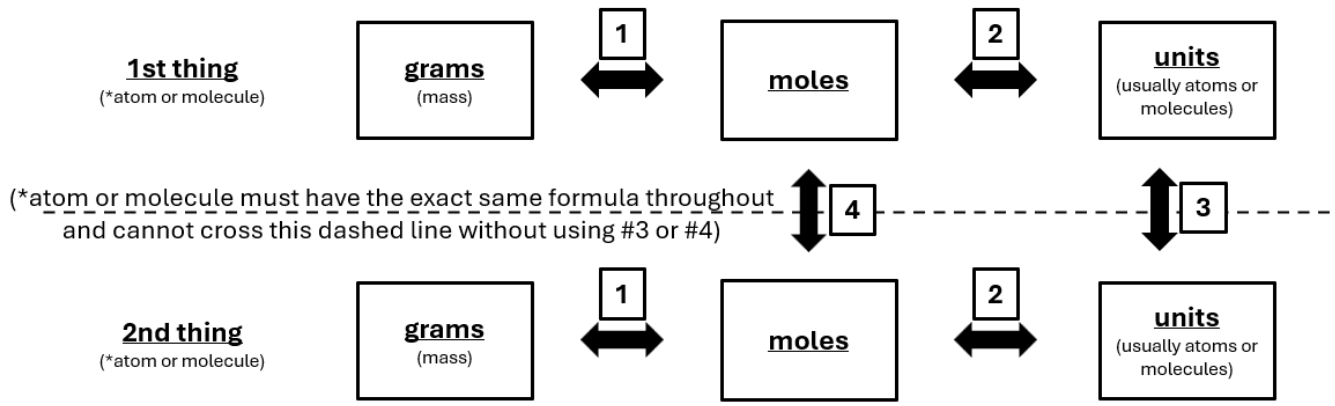
EXAMPLE 7.11

Relating Masses of Reactants

What mass of oxygen gas, O_2, from the air is consumed in the combustion of 702 g of octane, C_8H_{18}, one of the principal components of gasoline?

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





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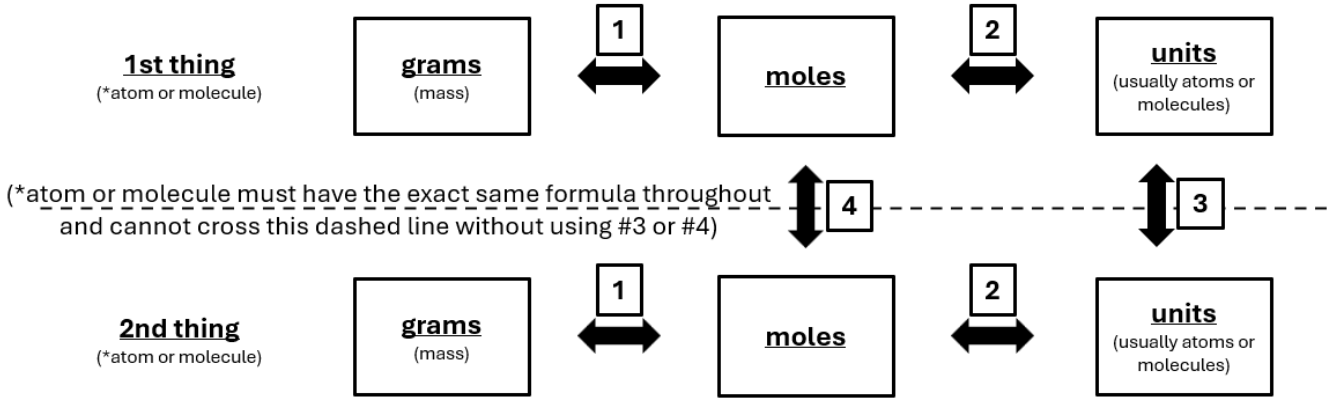
Check Your Learning

What mass of CO is required to react with 25.13 g of Fe_2O_3 according to the equation $Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$?

26	8	6
Fe	O	C
55.85	16.00	12.01
iron	oxygen	carbon



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Limiting Reactants

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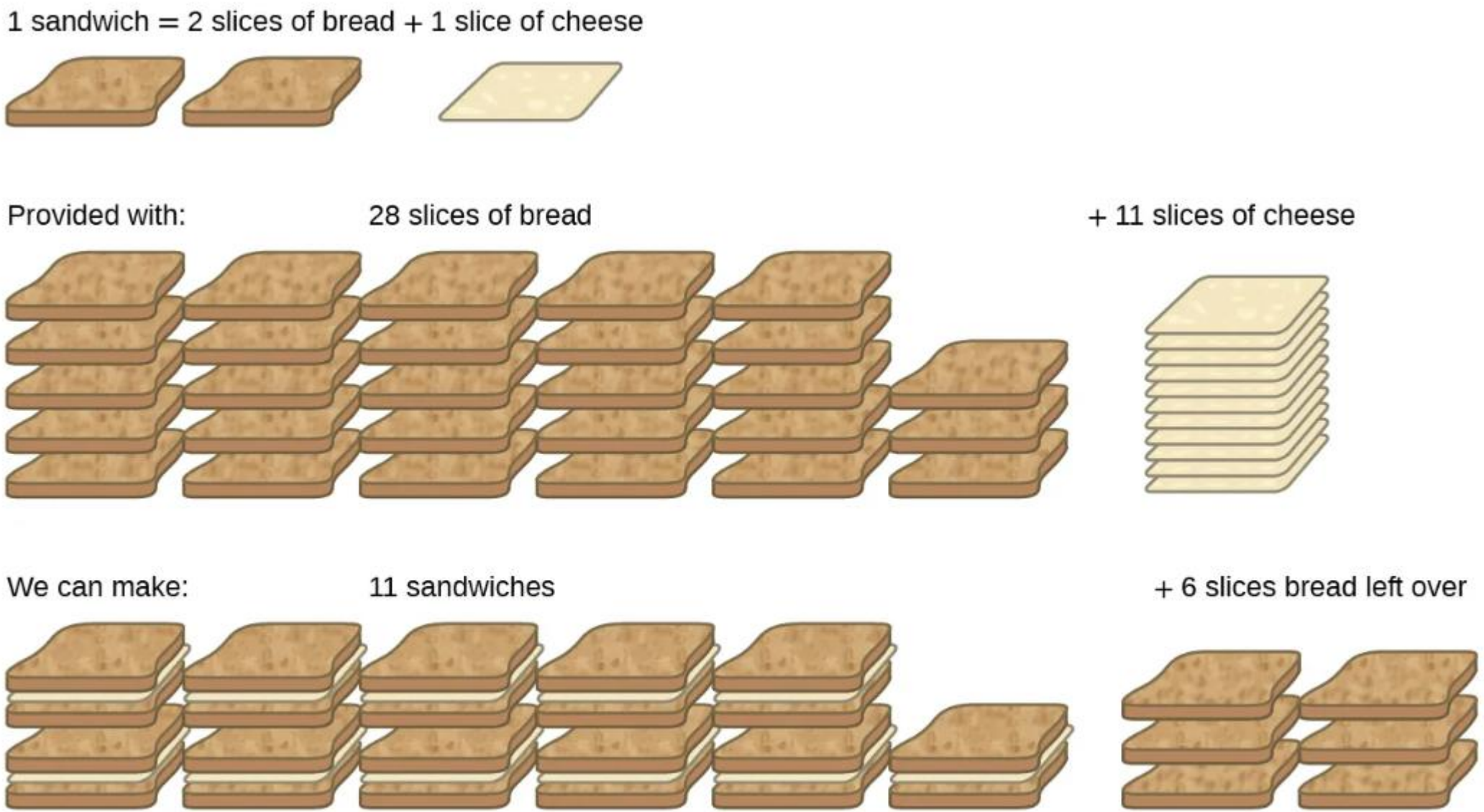


Figure 7.13 Sandwich making can illustrate the concepts of limiting and excess reactants.

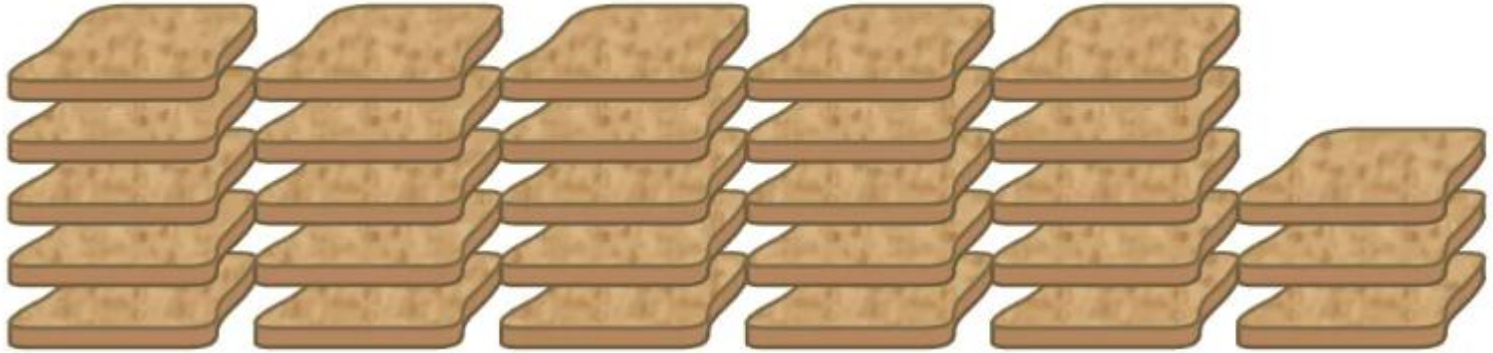
Test both reactants to see which is limiting.

Our recipe → 1 sandwich = 2 slices of bread + 1 slice of cheese

What we actually have → (example, just made this up)

- 28 slices of bread
- 11 slices of cheese

What we have → 28 slices of bread



Test ingredient 1 with unlimited of ingredient 2

+ Unlimited Cheese → 14 sandwiches

Since 14 sandwiches is more than 11 sandwiches, the bread is the excess ingredient

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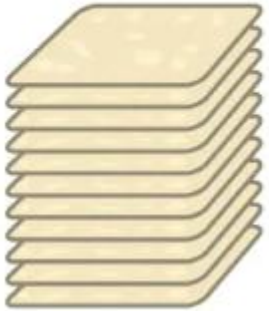
What we have → 11 slices of cheese



Test ingredient 2 with unlimited of ingredient 1

+ Unlimited Bread → 11 sandwiches

Since 11 sandwiches is less than 14 sandwiches, the cheese is the limiting ingredient

Test both reactants to see which is limiting.

Consider this concept now with regard to a chemical process, the reaction of hydrogen with chlorine to yield hydrogen chloride:

Our recipe → $H_2(g) + Cl_2(g) \longrightarrow 2HCl(g)$

What we actually have → (example, just made this up)

- 6 moles H_2
- 4 mole Cl_2

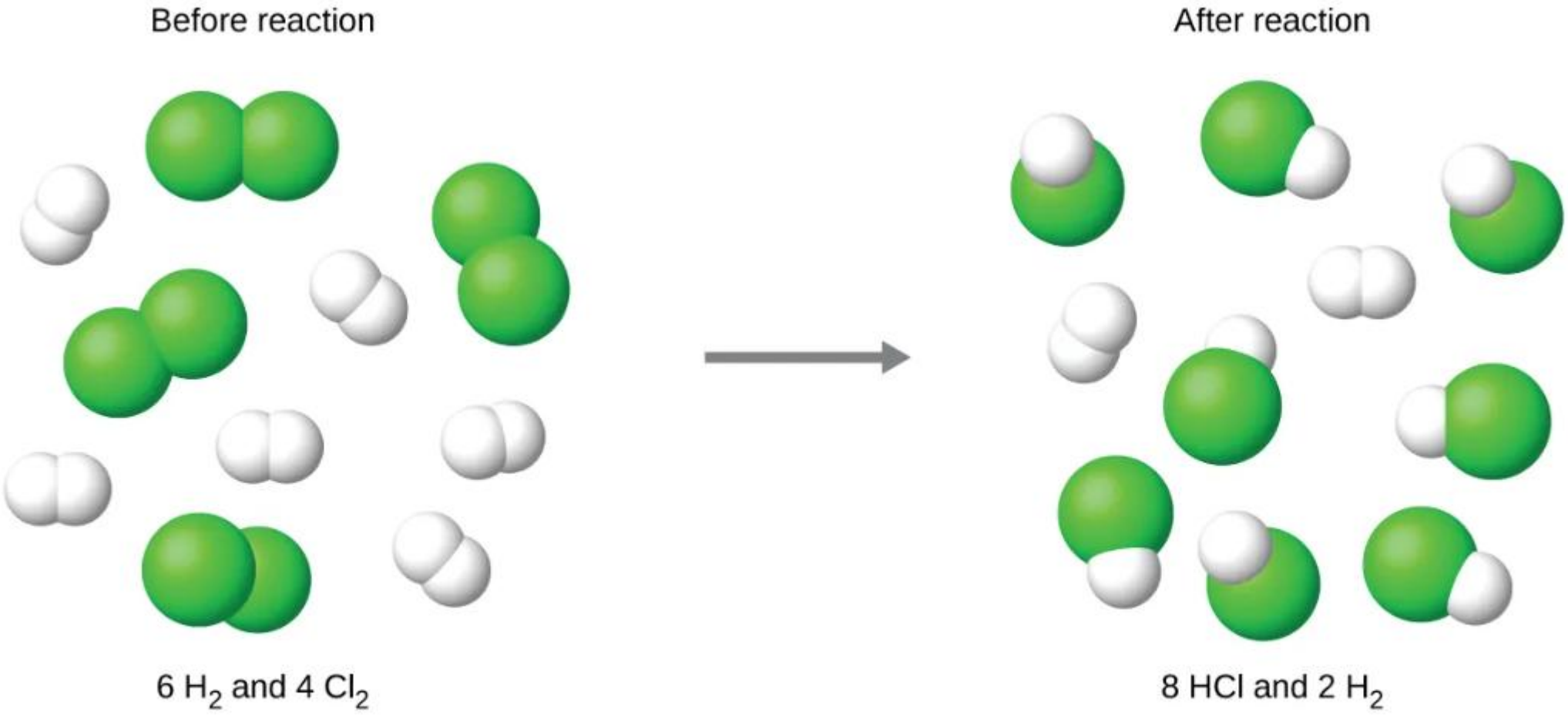


Figure 7.14 When H_2 and Cl_2 are combined in nonstoichiometric amounts, one of these reactants will limit the amount of HCl that can be produced. This illustration shows a reaction in which hydrogen is present in excess and chlorine is the limiting reactant.

Test both reactants to see which is limiting.

Consider this concept now with regard to a chemical process, the reaction of hydrogen with chlorine to yield hydrogen chloride:

Our recipe → $H_2(g) + Cl_2(g) \longrightarrow 2HCl(g)$

What we actually have → (example, just made this up)

- 3 moles H_2
- 2 mole Cl_2

What we have → 3 moles H_2

Test reactant 1 with unlimited of reactant 2

$$\text{mol HCl produced} = 3\ \text{mol H}_2 \times \frac{2\ \text{mol HCl}}{1\ \text{mol H}_2} = 6\ \text{mol HCl}$$

Since 6 mol HCl is more than 4 mol HCl, the H_2 is the excess ingredient

---

Test reactant 2 with unlimited of reactant 1

What we have → 2 mole Cl_2

$$\text{mol HCl produced} = 2\ \text{mol Cl}_2 \times \frac{2\ \text{mol HCl}}{1\ \text{mol Cl}_2} = 4\ \text{mol HCl}$$

Since 4 mol HCl is less than 6 mol HCl, the Cl_2 is the limiting reactant

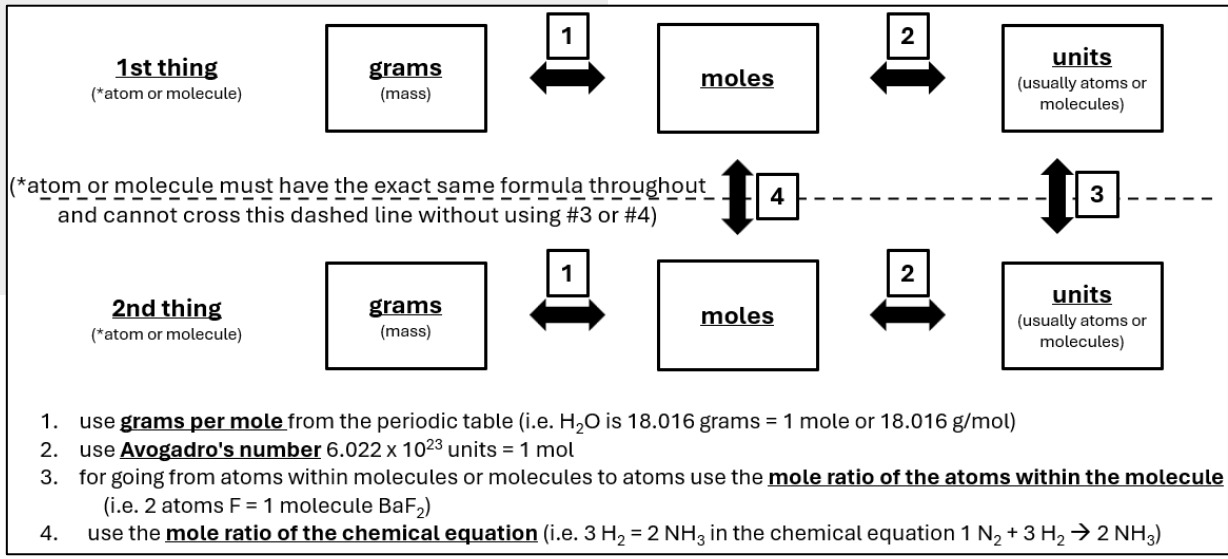
EXAMPLE 7.12

Identifying the Limiting Reactant

Silicon nitride is a very hard, high-temperature-resistant ceramic used as a component of turbine blades in jet engines. It is prepared according to the following equation:

$$3\mathrm{Si}(s) + 2\mathrm{N}_2(g) \longrightarrow \mathrm{Si}_3\mathrm{N}_4(s)$$

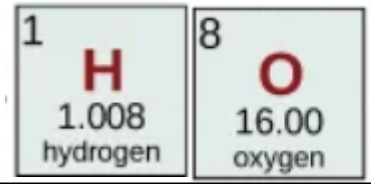
Which is the limiting reactant when 2.00 g of Si and 1.50 g of N_2 react?

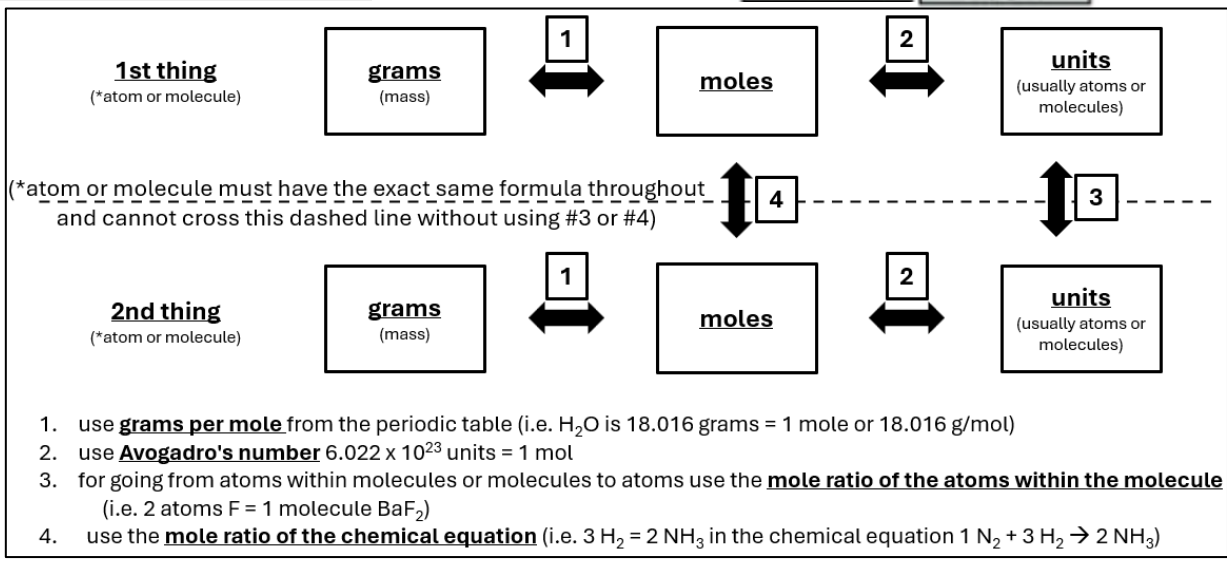


1. use **grams per mole** from the periodic table (i.e. H_2O is 18.016 grams = 1 mole or 18.016 g/mol)
2. use **Avogadro's number** 6.022×10^{23} units = 1 mol
3. for going from atoms within molecules or molecules to atoms use the **mole ratio of the atoms within the molecule** (i.e. 2 atoms F = 1 molecule BaF_2)
4. use the **mole ratio of the chemical equation** (i.e. 3 H_2 = 2 NH_3 in the chemical equation 1 N_2 + 3 H_2 → 2 NH_3)

Check Your Learning

Which is the limiting reactant when 5.00 g of H_2 and 10.0 g of O_2 react and form water?





1. use **grams per mole** from the periodic table (i.e. H_2O is 18.016 grams = 1 mole or 18.016 g/mol)
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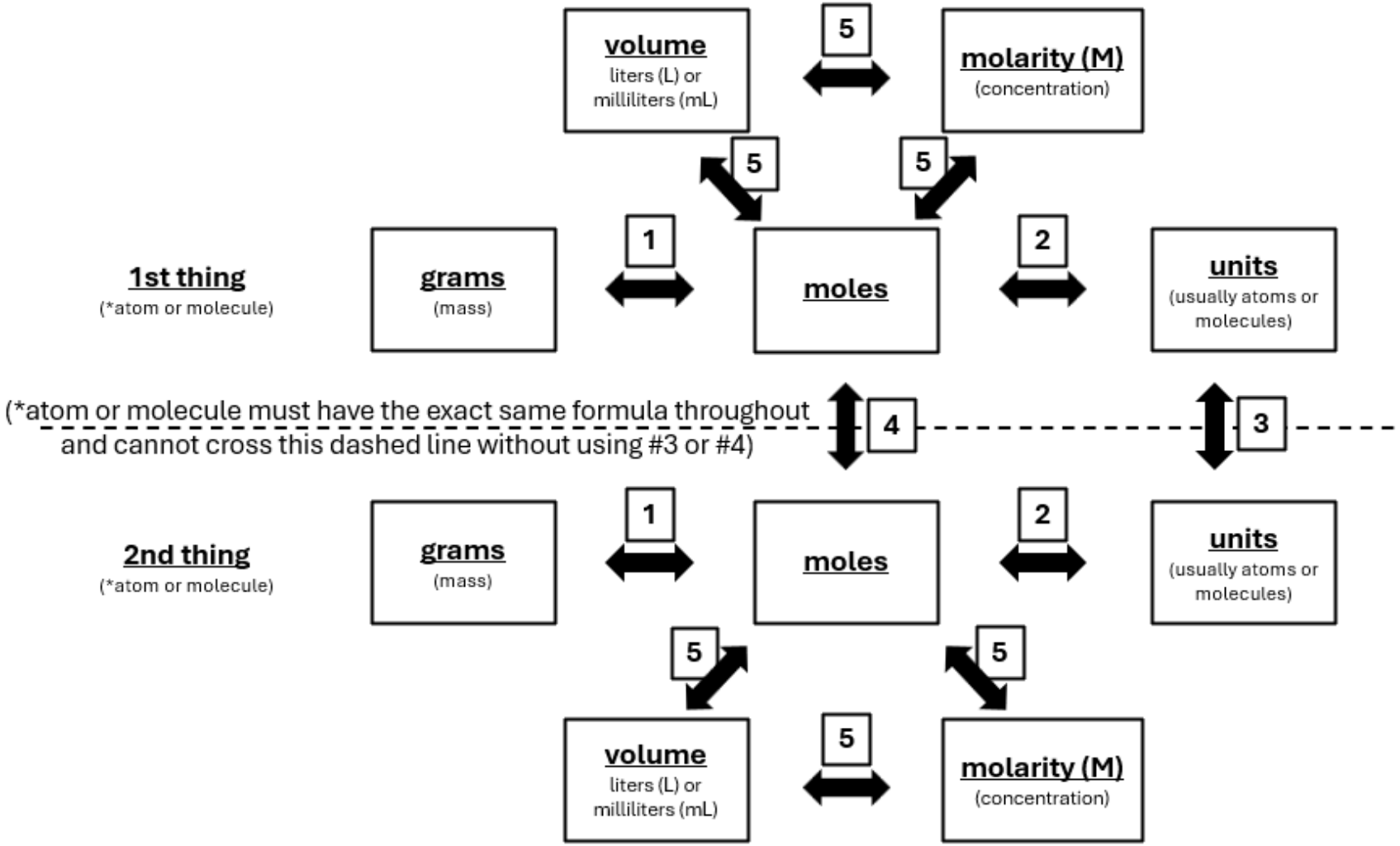
Quantitative Chemical Analysis

- Chapter 7.5 (Quantitative Chemical Analysis)

Adapted From: Paul Flowers, Edward J. Neth, William R. Robinson, PhD, Klaus Theopold, Richard Langley; Chemistry: Atoms First 2e; OpenStax; Feb 14, 2019; Houston Texas; https://openstax.org/books/chemistry-atoms-first-2e/pages/1-introduction

The molarity equation lets us convert moles to volume to M



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5. use the **molarity equation**: M = mol/L or L = mol/M or mol = M x L

The molarity equation lets us convert moles to volume to M

What volume of 0.0105-M HBr solution is required to titrate 125 mL of a 0.0100-*M* $Ca(OH)_2$ solution?

$Ca(OH_2)(aq) + 2HBr(aq) \rightarrow CaBr_2(aq) + 2H_2O(l)$

125 mL $Ca(OH_2)$
0.0100 M $Ca(OH_2)$

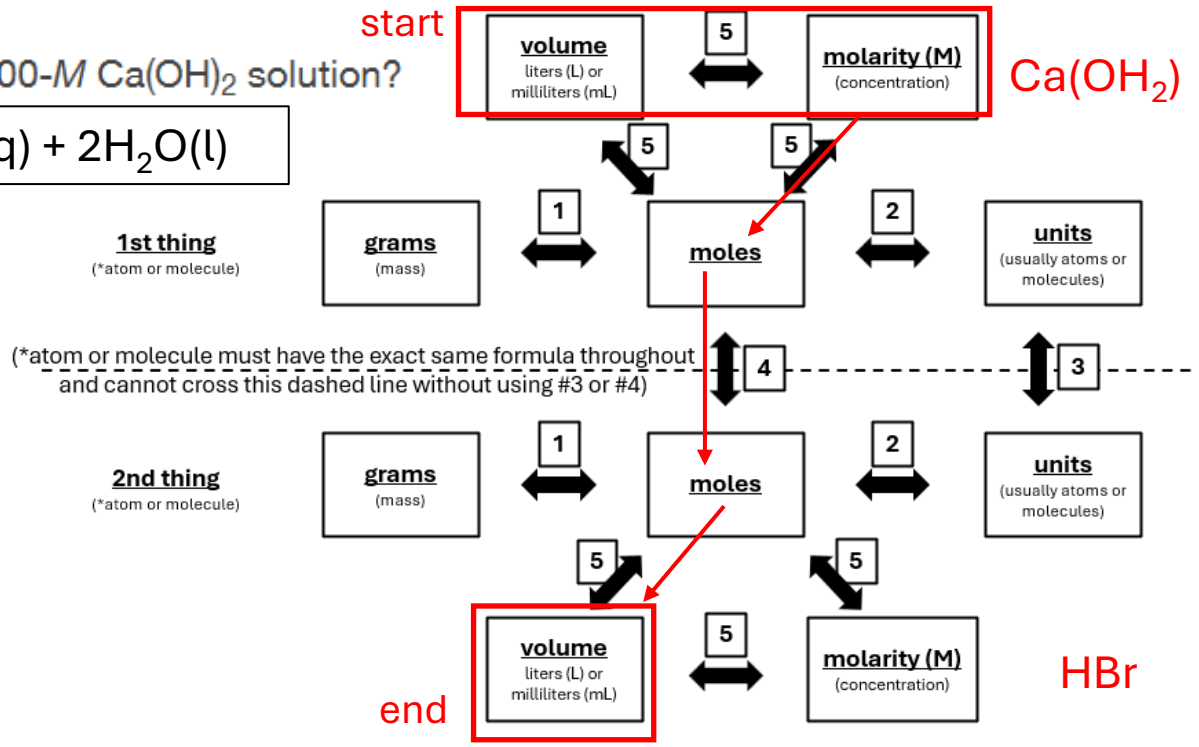
0.0105 M HBr

Step 1: Write one reactant or product on one side of the dotted line

Step 2: Write the other reactant or product on the other side of the dotted line

Step 3: Label your start and end points

Step 4: Move through the boxes only using the arrows and use the numbered conversion factors listed



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5. use the **molarity equation**: M = mol/L or L = mol/M or mol = M x L

convert mL to L

molarity/volume to moles

mol ratio of HBr to $Ca(OH)_2$

$$125\ \cancel{mL}\ Ca(OH_2) \times \frac{1\ L}{1000\ \cancel{mL}} \times 0.125\ L\ Ca(OH_2) \times 0.0100\ M\ Ca(OH)_2 = 0.00125\ mol\ \cancel{Ca(OH)_2} \times \frac{2\ mol\ HBr}{1\ mol\ \cancel{Ca(OH)_2}} =$$

0.00250 mol HBr

continued

mol to volume using M from problem

$$\frac{0.00250\ mol\ HBr}{0.0105\ M\ HBr} = 0.238\ L \text{ or } 238\ mL$$

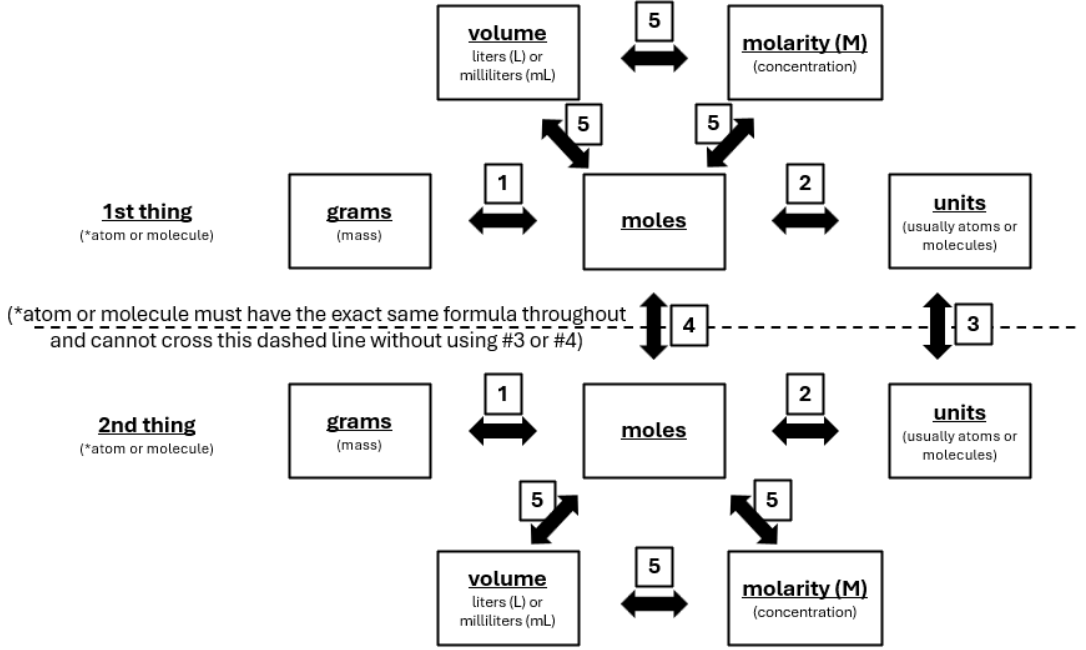
EXAMPLE 7.14

Titration Analysis

The end point in a titration of a 50.00-mL sample of aqueous HCl was reached by addition of 35.23 mL of 0.250 M NaOH titrant. The titration reaction is:

$$\mathrm{HCl}(aq) + \mathrm{NaOH}(aq) \longrightarrow \mathrm{NaCl}(aq) + \mathrm{H_2O}(l)$$

What is the molarity of the HCl?



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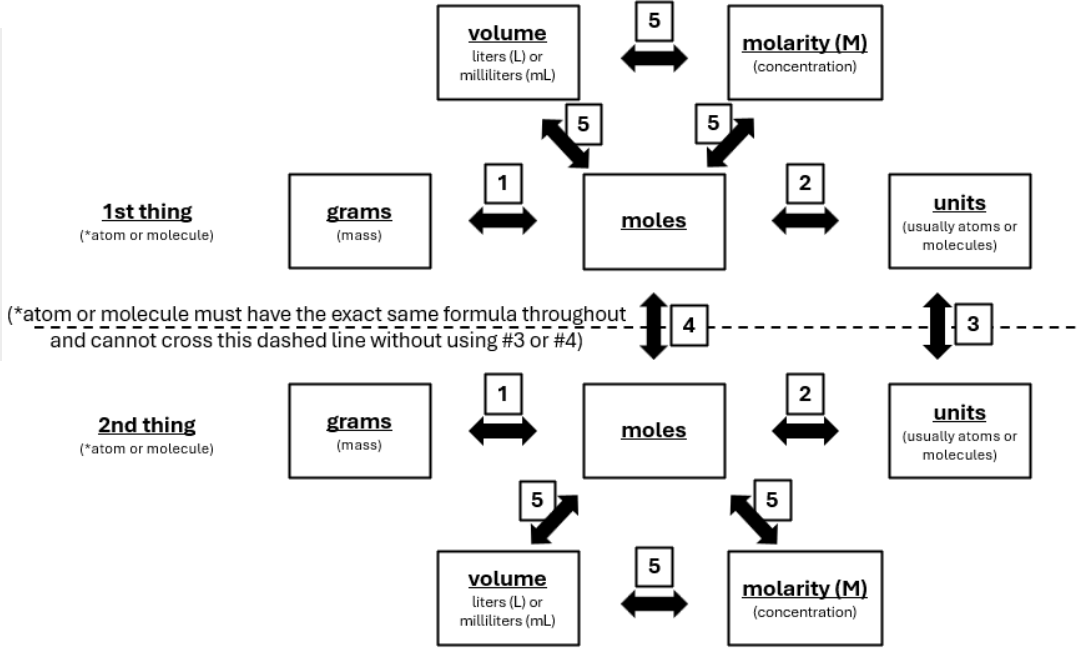
5. use the **molarity equation**: M = mol/L or L = mol/M or mol = M x L

Check Your Learning

A 20.00-mL sample of aqueous oxalic acid, $H_2C_2O_4$, was titrated with a 0.09113-*M* solution of potassium permanganate, $KMnO_4$ (see net ionic equation below).

$$2MnO_4^-(aq) + 5H_2C_2O_4(aq) + 6H^+(aq) \longrightarrow 10CO_2(g) + 2Mn^{2+}(aq) + 8H_2O(l)$$

A volume of 23.24 mL was required to reach the end point. What is the oxalic acid molarity?



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