CHEM 115
Masses and Moles

Lecture 5
Prof. Sevian

1

Facilitated Study Groups

- Tuesdays 3:20-4:20
- Wednesdays 11:00-12:00

Both FSGs are in Science, 1st floor, room 89 (also known as the chemistry conference room)

If you elect to join one, please commit to attending it for the entire semester

2

Agenda

- Practice some chemical nomenclature
- What is a mole? (money analogy)
- Converting between ways of measuring quantity of matter (mass ↔ moles)
- Empirical formulas
- Determining % composition (by mass) of each element given a chemical formula
- Determining empirical formula given % composition (by mass) of elements in a compound
- Determining molecular formula if given empirical formula and molar mass
- Chemical equations
  - Terminology: reactants, products
  - Using conservation of matter to balance chemical equations

3

A last note about naming compounds: Families of polyatomic ions

Chlorine family

- ClO^- (a.k.a. OCl^-)
- ClO_2^-
- ClO_3^-
- ClO_4^-

Chlorine family

- hypochlorite
- chlorite
- chlorate
- perchlorate

Bromine family

- BrO^- (a.k.a. OBr^-)
- BrO_2^-
- BrO_3^-
- BrO_4^-

Bromine family

- hypobromite
- bromite
- bromate
- perbromate

Clicker question #1 for today

What is the name of $(NH_4)_2S_2O_3$?

A. Nitrogen tetrahydrogen disulfur trioxide
B. Diammonium thiosulfate
C. Ammonium sulfoxide
D. Ammonium thiosulfate

5

Clicker question #2

What is the name of $FeCO_3$?

A. Iron carbonate
B. Iron (I) carbonate
C. Iron (II) carbonate
D. Iron (III) carbonate
E. Iron carboxide

6

Clicker question #3

What is the formula for copper (II) bromite?

A. Cu_2BrO
B. Cu_2BrO_2
C. $CuBrO_4$
D. $Cu(BrO_2)_2$
E. $Cu(BrO)_2$

7

Clicker question #4

What is the name of $H_2C_2O_4$?

A. Dihydrogen dicarbon tetroxide
B. Hydrogen oxalate
C. Oxalic acid
D. Carboxylic acid
E. Hydrogen carbon oxide

8

What is a Mole?

- Convenient way of counting particles
- Analogous to dozen, pair, gross, case, ream…
- One mole of particles always contains the same number of particles, regardless of the identity of the particle

1 mole of ☺ = 6.022×10^{23} particles of ☺ units

e.g., 1 *mol* Ar = 6.022×10^{23} Ar atoms

1 *mol* O_3 (*g*) = 6.022×10^{23} O_3 molecules

1 *mol* NaCl (*s*) = 6.022×10^{23} NaCl units

9

Moles scale from atoms

- How many atoms of O are in one unit of each of the following compounds?

H_2SO_4 $Ca(NO_3)_2$ $C_{12}H_{22}O_{11}$

- How many moles of O atoms are in 1 mol of each of the following compounds?

H_2SO_4 $Ca(NO_3)_2$ $C_{12}H_{22}O_{11}$

Possible conversions are:

$$\frac{6 \text{ mol O atoms}}{1 \text{ mol } Ca(NO_3)_2} \quad \text{or} \quad \frac{1 \text{ mol } Ca(NO_3)_2}{6 \text{ mol O atoms}}$$

11

What is the Mass of a Mole?

- Different kinds of particles have different masses
- Since the quantity of particles in a mole is the same for any particle, the mass of a mole of particles varies depending on the identity of the particles
- By definition,

$$1\ mol\ \text{of}\ {}^{12}_{6}\text{C particles} = 12\ g\ \underline{\underline{\text{exactly}}}$$

- Other molar masses always in reference to definition.

12

Molar Mass

Molar mass means the mass of one mole

- For monatomic elements, use atomic weight on the Periodic Table (remember what “atomic weight” means?)
- Examples:

  What is the mass of 1.000 mol of Ar?

$$1.000\ mol\ \text{Ar} \times \frac{39.95\ g\ \text{Ar}}{1\ mol\ \text{Ar}} = 39.95\ g\ \text{Ar}$$

  What is the mass of 2.5 mol of Xe?

$$2.5\ mol\ \text{Xe} \times \frac{131.3\ g\ \text{Xe}}{1\ mol\ \text{Xe}} = 328.25\ g\ \text{Xe}$$

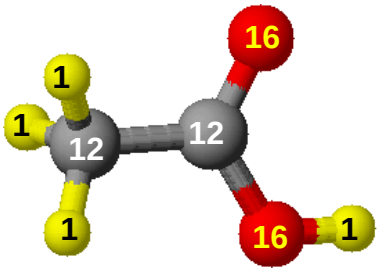
330 *g* Xe

13

What is the amount of money here?

How did you figure this out?

What is the amount of amu's here?



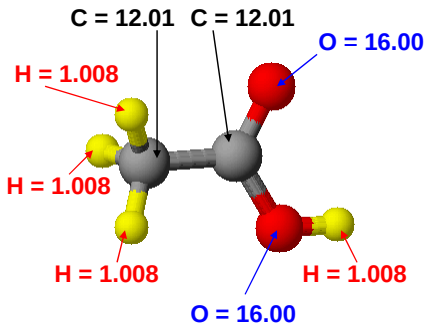
Answer:

60 amu

How did you figure this out?

15

Actually, the masses aren't integers



Mass of one molecule of CH_3COOH is

60.05 amu

Mass of 1 mole of CH_3COOH molecules is

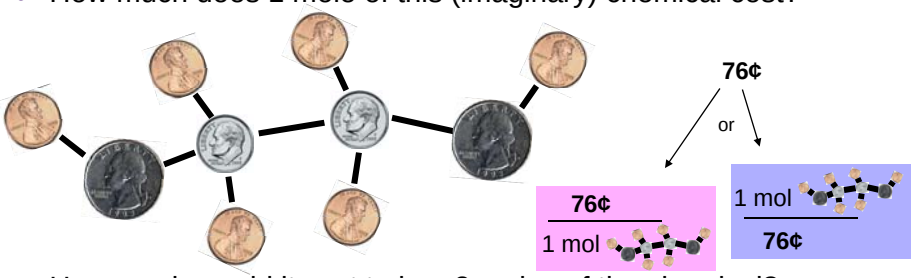
60.05 grams

Important note: Since there is always the same number of particles in a mole, when you determine the amu's of a unit, you are determining the mass in grams of a mole of that unit.

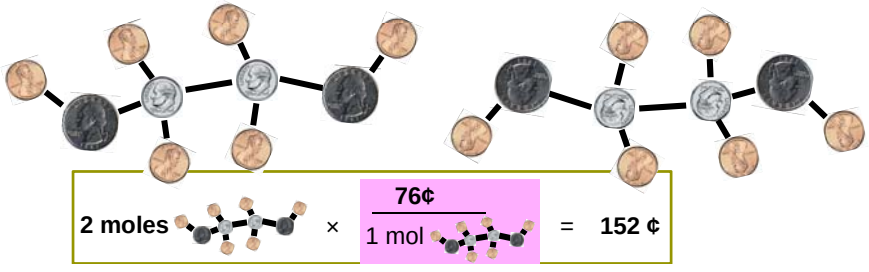
16

Q: How do mass – mole conversions work?
A: Just like money

- How much does 1 mole of this (imaginary) chemical cost?



- How much would it cost to buy 2 moles of the chemical?



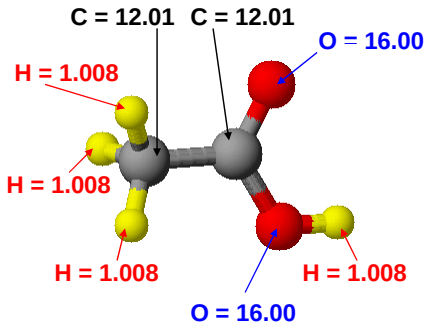
Moles and masses, so far

- Mass (in grams) of a mole is the same number as the mass (in amu) of one unit in the mole
- Use the average atomic weights on the periodic table as masses of individual atoms
- There are many names for this quantity:
  - Molar mass
  - Molecular weight (when the unit is a molecule)
  - Formula weight (when the unit is the simplest ratio of ions in an ionic crystal)

18

More on Molar Mass

What is the mass of 0.00497 mol of CH_3COOH?



Molar mass = 60.05 g/mol

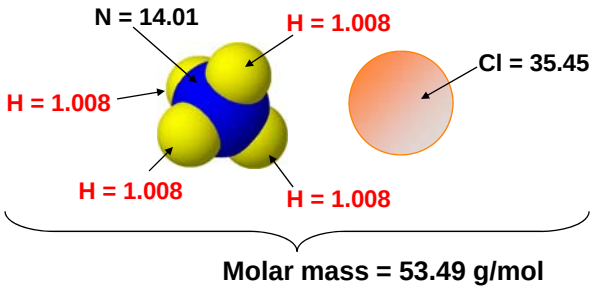
$$0.00497\ mol\ CH_3COOH \times \frac{60.05\ g}{1\ mol} = 0.298\ g\ CH_3COOH$$

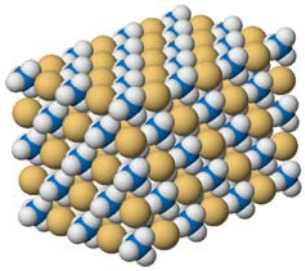
19

More on Molar Mass

- For ionic compounds, sometimes also called formula weight
- To determine molar mass (or formula weight) of one unit of ionic compound: sum the parts

Formula weight of NH_4Cl crystals: One unit is (one NH_4^+) plus (one Cl^-)





Hydrated Ionic Compounds

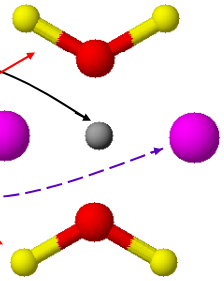
How many moles are in 5.55 g of $BaCl_2 \bullet 2H_2O$?

One unit of ionic formula consists of:

One Ba^{2+} ion = 137.3

Two Cl^- ions = 2 × 35.45

Two H_2O molecules = 2 × 18.02



Formula weight = 244.2 g/mol

$$5.55\ g\ BaCl_2 \bullet 2H_2O \times \frac{1\ mol}{244.2\ g} = 0.0227\ mol\ BaCl_2 \bullet 2H_2O$$

Conversions possible so far

(look for opportunities to use these in dimensional analysis)

- Moles ↔ mass (grams)
- Moles of atoms ↔ moles of a unit (e.g., molecule, neutral ionic crystal formula)
- Moles of something ↔ particles in the something

22

Combining molar mass and numbers of atoms

Example

How many atoms of hydrogen are in 1.63 grams of water (H_2O)?

$$1.63\ \text{g } H_2O \times \frac{?\ \text{something}}{?\ \text{g } H_2O} \times \frac{?\ \text{another thing}}{?\ \text{something}} \times \frac{?\ \text{atoms of H}}{?\ \text{another thing}} = ?\ \text{atoms of H}$$

$$1.63\ \text{g } H_2O \times \frac{1\ \text{mol } H_2O}{18.02\ \text{g } H_2O} \times \frac{6.022 \times 10^{23}\ \text{molecules of } H_2O}{1\ \text{mol } H_2O} \times \frac{2\ \text{atoms of H}}{1\ \text{molecule of } H_2O} = 1.09 \times 10^{23}\ \text{atoms of H}$$

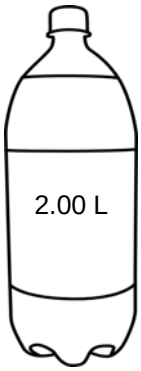
3 sig figs

3 sig figs

How Many Molecules?

Too many to count!

How many molecules of water are in a 2.00-L bottle that is filled with water? Water has a density of 1.000 g/mL.



Start **End**

2.00 L of H_2O

$$\frac{}{1} \times \frac{1000\ mL}{1\ L} \times \frac{1.000\ g}{1\ mL} \times \frac{1\ mol}{18.02\ g} \times \frac{6.022 \times 10^{23}\ molecules}{1\ mol} = \frac{}{1}$$

6.68×10^{25} molecules of H_2O

Composition of a …

- Can be:
  - Composition of compounds in a mixture
  - Composition of elements in a compound
  - Composition of ions or molecules in a complex ion
- Usually composition is given in mass percent (also called weight %)
- Use the chemistry definition of percent

$$\% = \frac{part}{whole} \times 100\%$$

- Know the difference between fraction and percent – a fraction can be expressed as a percent by multiplying by 100 ("percent" means part out of 100)

Fraction 0.7585 is the same as 75.85%

Composition of a Mixture

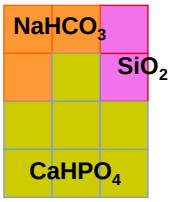
Baking powder is a mixture of ingredients. A sample of baking powder contains 3.50 g of calcium hydrogen phosphate ($CaHPO_4$), 1.50 g of sodium bicarbonate ($NaHCO_3$), and 1.00 g of silicon dioxide (SiO_2). Calculate the percent composition by mass.

$$\%\mathrm{CaHPO_4} = \frac{3.50g}{3.50+1.50+1.00g} \times 100\% = 58.3\%$$

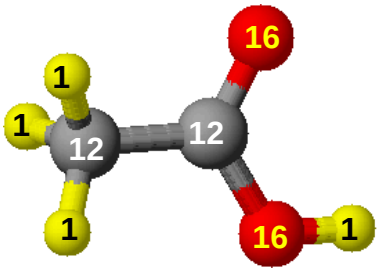
$$\%\mathrm{NaHCO_3} = \frac{1.50g}{6.00g} \times 100\% = 25.0\%$$

$$\%\mathrm{SiO_2} = 100 - (58.3 + 25.0)\% = 16.7\%$$

A picture of the mixture (to assist in estimating)



What does % composition mean?



Note: These are approximate atomic masses, for the purpose of demonstrating % composition. When actually calculating % composition, use the values from the Periodic Table.

% Composition by Mass

$$fraction\ \mathrm{C} = \frac{2\times12}{60} = 40.\%$$

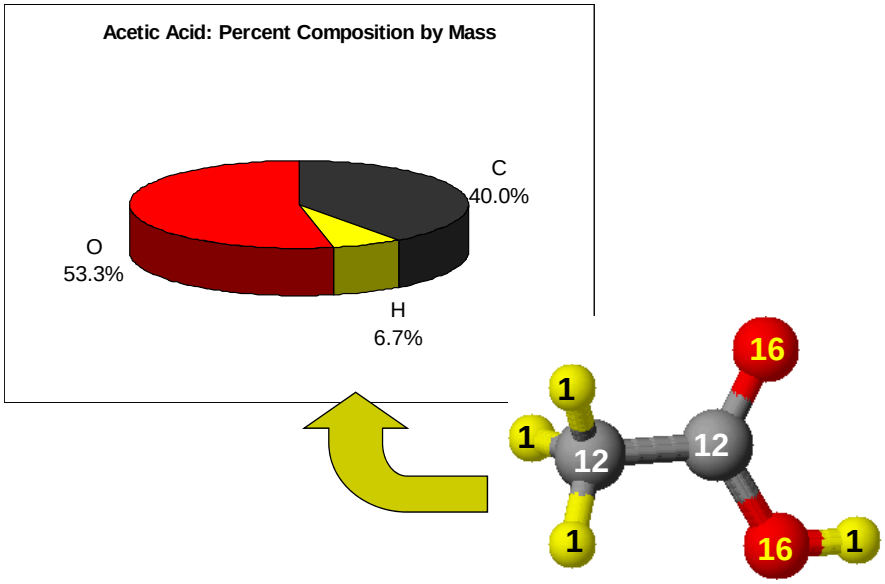
$$fraction\ \mathrm{H} = \frac{4\times1}{60} = 6.7\%$$

$$+\quad fraction\ \mathrm{O} = \frac{2\times16}{60} = 53.3\%$$

40% + 6.7% + 53.3% = 100%

check

What does % composition mean?



Composition of a Compound

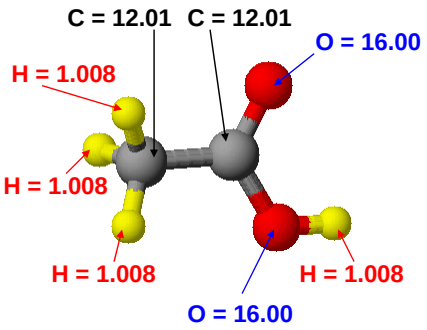
What is the composition by mass of acetic acid (CH_3COOH)?

$$\%C = \frac{24.02}{60.05} \times 100\% = 40.00\%$$

$$\%H = \frac{4.032g}{60.05g} \times 100\% = 6.714\%$$

$$\%O = \frac{32.00g}{60.05g} \times 100\% = 53.29\%$$

$$Check: 40.00 + 6.714 + 53.29 = 100.00\%$$



Recall from earlier:
Molar mass = 60.05 g/mol

Composition of a Hydrated Compound

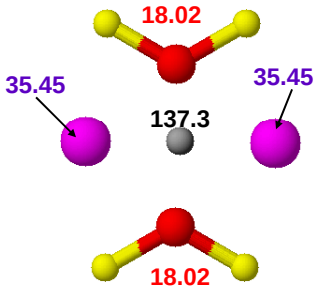
Heating barium chloride dihydrate ($BaCl_2 \bullet 2H_2O$) drives off the water, leaving the anhydrous compound ($BaCl_2$). The chemical reaction is

$$BaCl_2 \bullet 2H_2O\ (s) \rightarrow BaCl_2\ (s) + 2\ H_2O\ (g)$$

If you begin with a 10.0 g sample of the hydrated compound, what mass of water will be lost?

$$\%H_2O = \frac{2 \times 18.02}{244.2} \times 100\% = 7.379\%$$

$$\begin{aligned} \text{mass of } H_2O \text{ in sample} &= 7.379\% \text{ of } 10.0\ g \\ &= 0.07379 \times 10.0 g \\ &= 0.738 g \end{aligned}$$



Formula weight = 244.2 g/mol

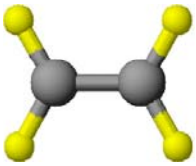
Problem solving strategies

- Ascertain whether the problem looks like a percent composition or empirical formula problem - there are only two directions to go:
  1. converting mass to moles (and then ratios of moles), or
  2. converting (ratios of) moles to mass (and then % by mass)
- What information is given?
- What information is sought?
- Strategize (it is helpful to draw pictures):
  - masses or percentages given: this is a mass to moles problem
  - chemical formula given: this is a moles to mass problem

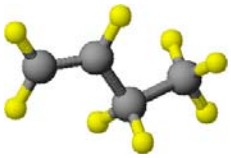
32

Chemical Compounds and Mass

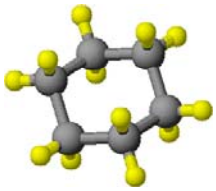
- Chemical formula to percent composition
  - Need to determine parts and whole
  - Use definition of percent
- Going the other direction
  - Percent composition alone is not enough information to determine molecular formula



C_2H_4



C_4H_8



C_6H_{12}

All three of these have 14.37% H and 85.63% C by mass

33

Empirical Formula

Lowest whole number ratio of elements in a chemical formula

Chemical formula	Empirical formula
C_2H_4	CH_2
C_4H_8	CH_2
C_6H_{12}	CH_2
$C_6H_{12}O_6$	
$Na_2C_2O_4$	
CH_3COOH	
H_2O_2	
H_2O	

34

Chemical Compounds and Mass

- Chemical formula to percent composition
  Ratio of moles → Percent by mass

- Percent composition (or relative masses) to empirical formula
  Percent by mass → Ratio of moles

35

Step 1: % Composition to Empirical Formula

Analysis of a particular compound shows that it is composed of X% carbon, Y% hydrogen, and Z% oxygen.
What is the compound's empirical formula?

M A S S (*grams*) ⇒ M O L E S (*mol*)

$$\left.\begin{array}{l} \dfrac{\text{X } grams}{100\ grams}\ \text{are carbon} \\ \dfrac{\text{Y } grams}{100\ grams}\ \text{are hydrogen} \\ \dfrac{\text{Z } grams}{100\ grams}\ \text{are oxygen} \end{array}\right\} \Rightarrow \left\langle \begin{array}{l} \text{specific whole number ratio of} \\ moles\ \text{C} : moles\ \text{H} : moles\ \text{O} \\ \text{is a : b : c} \\ \text{empirical formula is } \text{C}_a\text{H}_b\text{O}_c \end{array}\right.$$

M A S S (*grams*) ⇒ M O L E S (*mol*)

Step 1: % Composition to Empirical Formula

Analysis of a particular compound shows that it is composed of 73.14% carbon, 7.37% hydrogen, and the remainder is oxygen. What is the compound's empirical formula?

$$\frac{73.14\ g\ \text{C}}{} \times \frac{1\ mol\ \text{C}}{12.01\ g} = 6.089\ mol\ \text{C}$$

$$\frac{7.37\ g\ \text{H}}{} \times \frac{1\ mol\ \text{H}}{1.008\ g} = 7.31\ mol\ \text{H}$$

$$\frac{19.49\ g\ \text{O}}{} \times \frac{1\ mol\ \text{O}}{16.00\ g} = 1.218\ mol\ \text{O}$$

$\Rightarrow$

specific whole number ratio of *moles* C : *moles* H : *moles* O is 6.089 : 7.31 : 1.218

$$= \frac{6.089}{1.218} : \frac{7.31}{1.218} : \frac{1.218}{1.218}$$

$$= 5 : 6 : 1$$

so, empirical formula is $C_5H_6O_1$

Variations on Determining Empirical Formula

- Start with % composition of elements in a compound
- Start with masses of elements in a compound
- Start with % or masses of parts of a hydrated compound (*e.g.*, determine *n* in $CuSO_4 \cdot nH_2O$, given mass of $CuSO_4$ and mass of H_2O lost when compound is heated)

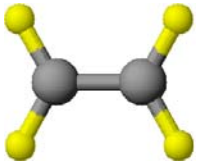
39

Step 2: Empirical Formula to Molecular Formula

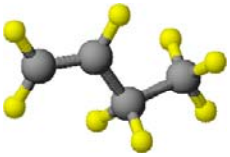
- A hydrocarbon has 85.63% carbon by mass. What is its empirical formula?

CH_2

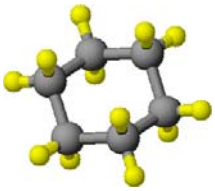
- What else do you need to know to determine molecular formula?



C_2H_4



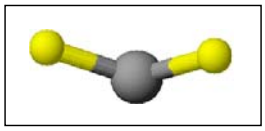
C_4H_8



C_6H_{12}

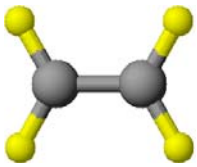
(All three have 14.37% H and 85.63% C by mass)

How many empirical formulas?

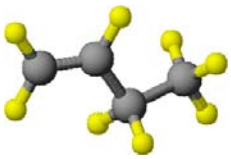


Empirical Unit CH_2

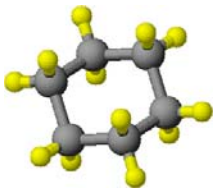
Mass is 12.01 + 2(1.008) = 14.03 g/mol



C_2H_4



C_4H_8



C_6H_{12}

$2 \times (CH_2)$	$4 \times (CH_2)$	$6 \times (CH_2)$
$= 2 \times (14.03)$	$= 4 \times (14.03)$	$= 6 \times (14.03)$
$= 28.06$ g/mol	$= 56.12$ g/mol	$= 84.18$ g/mol

What we have learned so far

- Moles are a counting group
- Mass and moles are two different measures of the quantity of matter
  - Mass is what you measure in the lab (use a scale or mass balance)
  - Moles are a count of how many particles (can't be measured directly)
  - The two are connected because each particle has a mass which depends on what the particle is made of
- There are lots of ways to torture chemistry students with using mass to moles conversions
  - What is the molar mass of a compound?
  - How many moles are in a particular mass of compound? (and vice versa)
  - What is the % composition by mass of the different elements in a particular compound?
  - What is the empirical formula of a compound that has a particular set of % composition (by mass) of elements?
  - What is the molecular formula if you know empirical formula and molar mass?
  - Combinations of the above

i>clicker

Clicker question #5

What kind of problem is this - what strategy would you use?

> Serotonin is a compound that conducts nerve impulses in the brain. It contains 68.2 mass percent C, 6.86 mass percent H, 15.9 mass percent N, and the rest O. Its molar mass is 176 g/mol. Determine its molecular formula.

A. Take the ratio of 68.2 : 6.86 : 15.9 : whatever part O, convert to whole numbers to get molecular formula
B. Divide each percentage (as grams) by 176 to get moles, then take ratio
C. Assume 100 g so %'s are grams, convert to moles, then take ratio of moles
D. Assume 1 mol, calculate mass of each element in 179 g, then convert those masses to number of moles to get ratio of moles

43