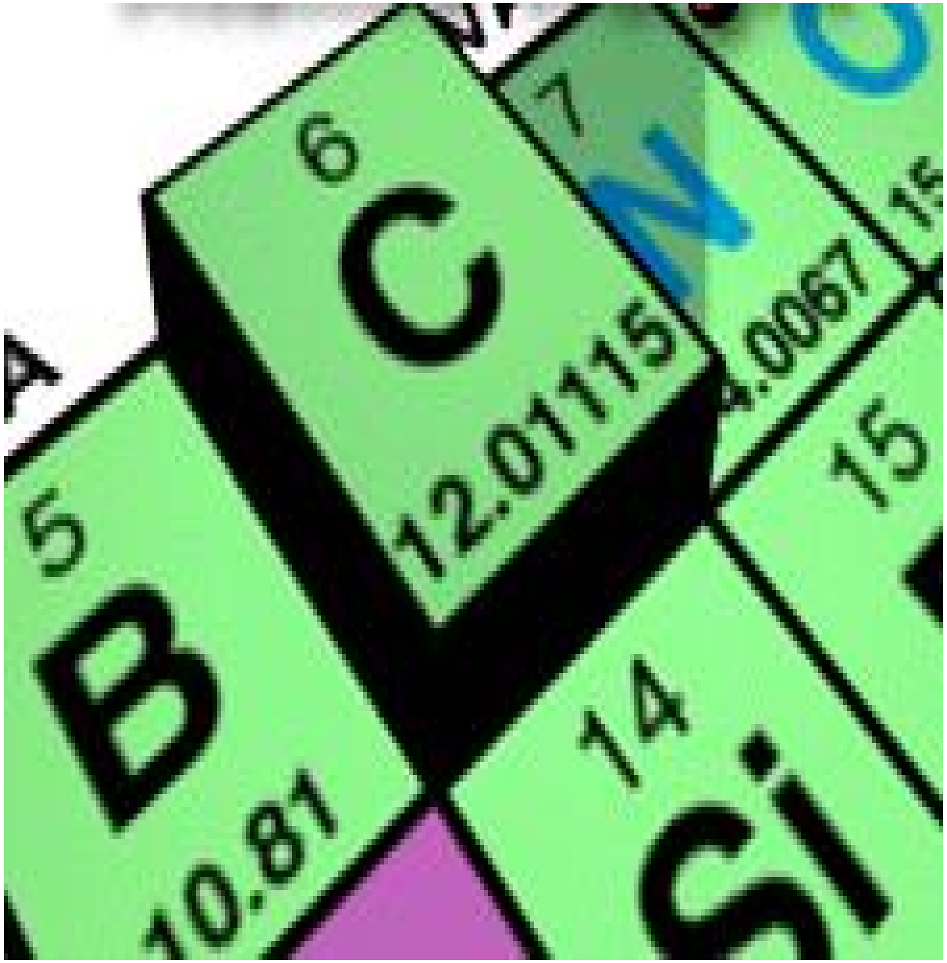


Atomic Masses, the Mole and Percent Composition

Guess the number of M&Ms in this jar?

Knowing the average mass of an M & M (so we can assume they all have this weight); the weight of the jar and its contents would allow you to come pretty close to the correct number of M&Ms in the jar instead of counting all of this candy.

Chemists need to know how many atoms are taking part in the reactions they perform but atoms cannot be weighed as M&Ms can but the average mass of atoms still is required.

Mass spectrometer

The mass of all other atoms is expressed **relative** to that of ^{12}C which is **assigned a mass of 12 atomic mass units** (amu).

An exact number

Relative Atomic Mass

Mass spectrometer provides **ratio** of masses.

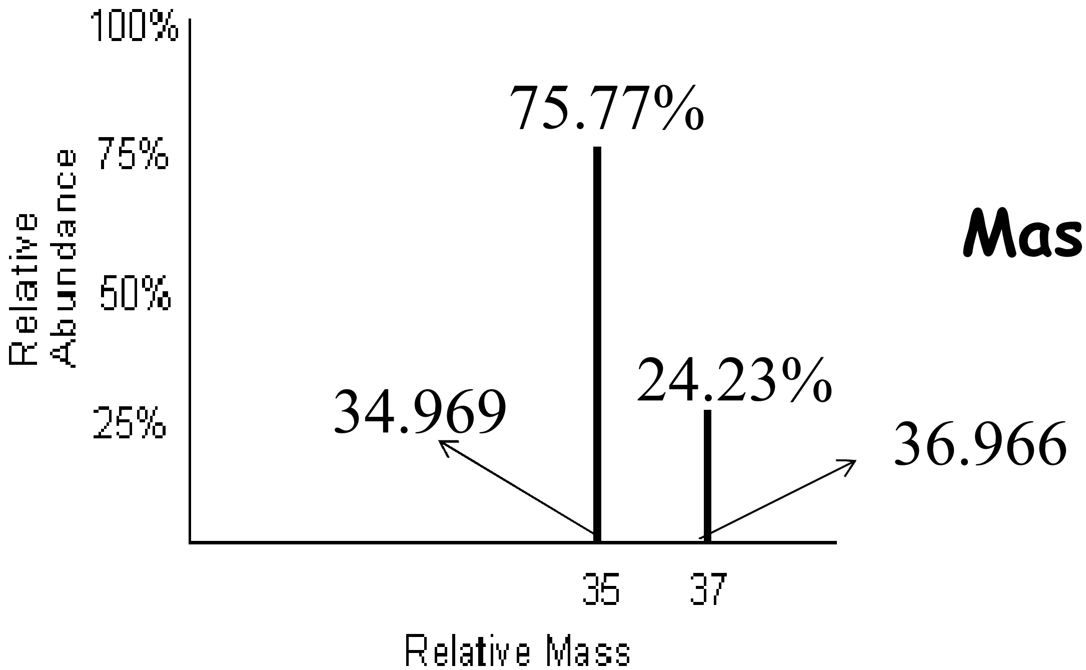
Example

$$\frac{\text{Mass } ^{13}C}{\text{Mass } ^{12}C} = 1.0836129$$

No units

Mass ^{13}C = 1.0836129 x 12 amu = 13.003355 amu

Average Atomic Mass of an Atom



Mass Spectrum of Chlorine

This value appears in Periodic Table

Average atomic mass of chlorine:

(75.77% x 34.969 amu) + (24.23% x 36.966 amu) = 35.453 amu

These values do not appear in Periodic Table

The Periodic Table

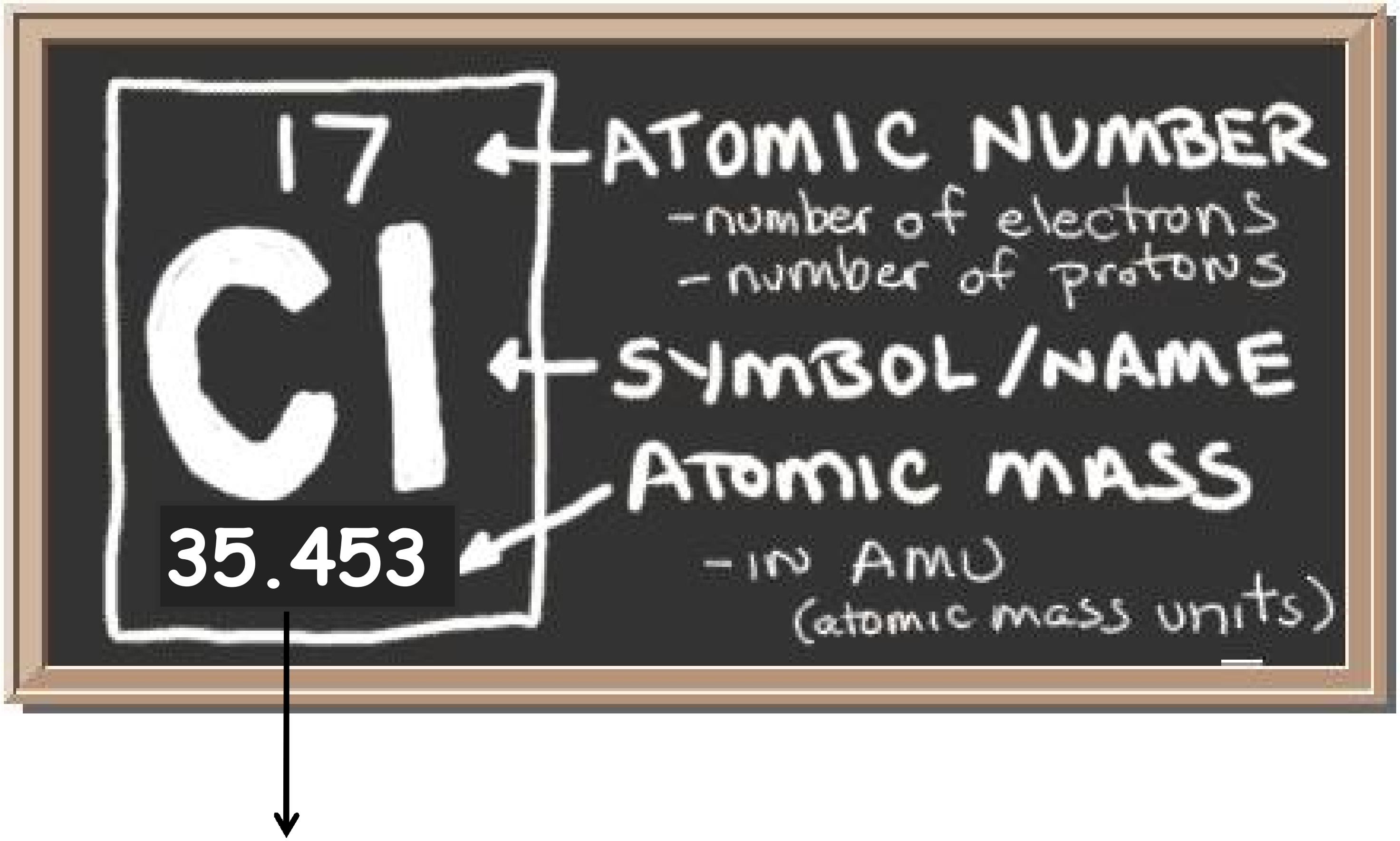
Key:

element name atomic number **symbol** atomic weight (mean relative mass)

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*lanthanoids	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**actinoids	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Periodic Table Information for Chlorine



Atomic mass obtained by taking average atomic masses of natural occurring isotopes of that element.

Natural Percent Abundance of Stable Isotopes of Some Elements

Name	Symbol	Natural percent abundance	Mass (amu)	"Average" atomic mass
Hydrogen	$^{1}_{1}H$	99.985	1.0078	
	$^{2}_{1}H$	0.015	2.0141	1.0079
	$^{3}_{1}H$	negligible	3.0160	
Helium	$^{3}_{2}He$	0.0001	3.0160	4.0026
	$^{4}_{2}He$	99.9999	4.0026	
Carbon	$^{12}_{6}C$	98.89	12.000	12.011
	$^{13}_{6}C$	1.11	13.003	
Nitrogen	$^{14}_{7}N$	99.63	14.003	14.007
	$^{15}_{7}N$	0.37	15.000	
Oxygen	$^{16}_{8}O$	99.759	15.995	
	$^{17}_{8}O$	0.037	16.995	15.999
	$^{18}_{8}O$	0.204	17.999	
Sulfur	$^{32}_{16}S$	95.002	31.972	
	$^{33}_{16}S$	0.76	32.971	32.06
	$^{34}_{16}S$	4.22	33.967	
	$^{36}_{16}S$	0.014	35.967	
Chlorine	$^{35}_{17}Cl$	75.77	34.969	35.453
	$^{37}_{17}Cl$	24.23	36.966	
Zinc	$^{64}_{30}Zn$	48.89	63.929	
	$^{66}_{30}Zn$	27.81	65.926	
	$^{67}_{30}Zn$	4.11	66.927	65.38
	$^{68}_{30}Zn$	18.57	67.925	
	$^{70}_{30}Zn$	0.62	69.925	

Chemists use a counting unit called the mole that allows them to count particles (atoms, molecules, ions, etc.) that take part in millions of chemical reactions.

One dozen eggs = 12 eggs

One grand = 1000 dollars

One mole = amount of a substance that contains

6.022×10^{23} particles or units

Amedeo Avogadro

Wow! This is a really big number!

$$6.022 \times 10^{23}$$

Avogadro's number (N_A)

602200000000000000000000

Avogadro's number <u>in seconds</u> is approximately

19 quadrillion years!

12.01 g of C contains 6.022×10^{23} atoms of C

1 mole of carbon has a mass of 12.01g

16.00 g O contains 6.022×10^{23} atoms of O

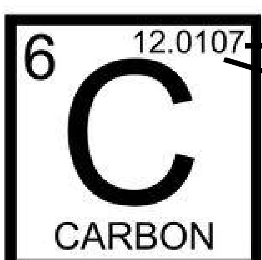
1 mole of oxygen has a mass of 16.00g

1.008 g H contains 6.022×10^{23} atoms of H

1 mole of hydrogen has a mass of 1.008 g

Note: Different masses of atoms BUT

SAME number of atoms



Average atomic mass of carbon

Mass of 1 mole of carbon

Molar Mass

A substance's molar mass is the mass of one mole of the substance expressed in grams.

An atom's molar mass is equal to the average atomic mass of the atom which can be found in the periodic table. This value is expressed in grams per mole (g/mol).

C = 12.01 g/mol

O = 16.00 g/mol

H = 1.008 g/mol

What is the molar mass of a molecule?

Sum of average atomic masses of all atoms in the molecular formula of a compound expressed in grams per mole (g/mol).

The **molecular formula** of a covalent compound states the number and type of each atom present.

Example: Determination of the molar mass of ammonia

Molecular formula of ammonia: NH_3

Average atomic mass of each atom in the molecular formula:

Atom	Atomic mass
N	14.01
3 H	1.008 x 3

Molar mass of ammonia = 14.01 + (3 x 1.008) = 17.03 g/mol

Conversions Between Moles, Masses and Number of Particles

Example: How many molecules of glucose, $C_6H_{12}O_6$, are in 15 g of glucose and how many moles does this mass represent?

Solution

Have: mass of glucose **Want**: (i) molecules of glucose

(ii) moles of glucose

Molar mass of $C_6H_{12}O_6$: (6 x 12.01) + (6 x 16.00) + (12 x 1.008)

6 mol C + 6 mol O + 12 mol H

= **180.16** g/mol

Unit equivalents: 1 mol $C_6H_{12}O_6$ = 6.022 x 10^{23} molecules

180.16 g $C_6H_{12}O_6$ = 1 mol $C_6H_{12}O_6$

6.022 x 10^{23} molecules $C_6H_{12}O_6$ = 180.16 g $C_6H_{12}O_6$

Using dimensional analysis to solve this problem:

(i) 15 ~~g $C_6H_{12}O_6$~~ x $\frac{6.022 \times 10^{23} \text{ molecules}}{180.16 \text{ ~~g } C_6H_{12}O_6}$ = 5.0 x 10^{22} molecules of glucose

6.022 x 10^{23} molecules $C_6H_{12}O_6$ = 180.16 g $C_6H_{12}O_6$

(ii) 15 ~~g $C_6H_{12}O_6$~~ x $\frac{1 \text{ mol } C_6H_{12}O_6}{180.16 \text{ ~~g } C_6H_{12}O_6}$ = 0.083 mol $C_6H_{12}O_6$

180.16 g $C_6H_{12}O_6$ = 1 mol $C_6H_{12}O_6$

Percent Composition

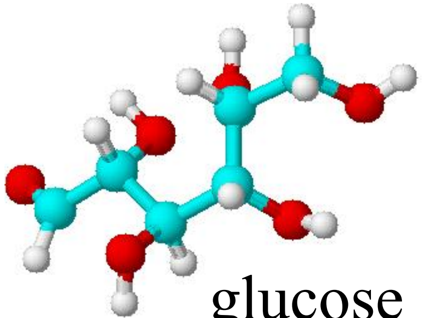
The percent composition of a component in a compound is the percent of the total mass of the compound that is due to that component.

Calculating Percent Composition

1. Calculate the molar mass of the compound.
2. Calculate the mass of the required component in the compound.
3. Divide the mass of this component by the total molar mass of the compound and multiply by 100.

$$\text{Percent Composition} = \frac{\text{Mass due to specific component}}{\text{Total molar mass of compound}} \times 100$$

$C_6H_{12}O_6$



glucose

Percent composition

% (by mass) of each element

molar mass = 180.16 g/mol

$$\frac{6 \text{ mol C}}{\text{mol } C_6H_{12}O_6} = \frac{(6 \text{ x } 12.01 \text{ g/mol})}{(1 \text{ x } 180.16 \text{ g/mol})} = 0.4000 = 40.00\% \text{ C}$$

$$\frac{12 \text{ mol H}}{\text{mol } C_6H_{12}O_6} = \frac{(12 \text{ x } 1.008 \text{ g/mol})}{(1 \text{ x } 180.16 \text{ g/mol})} = 0.06714 = 6.714\% \text{ H}$$

$$\frac{6 \text{ mol O}}{\text{mol } C_6H_{12}O_6} = \frac{(6 \text{ x } 16.00 \text{ g/mol})}{(1 \text{ x } 180.16 \text{ g/mol})} = 0.5329 = 53.29\% \text{ O}$$

Types of Formulae

- **Empirical Formula**: expresses the *smallest whole number ratio* of the atoms present.

- **Molecular Formula**: states the *actual* number of each kind of atom found in *one molecule* of the compound.

Example of Empirical Formula Calculation

A sample of a brown gas, a major air pollutant, is found to contain 2.34 g N and 5.34 g O.

Determine an empirical formula for this substance.

Solution:

$$\text{moles of N} = \frac{2.34\,\cancel{g}\text{ of N}}{14.01\,\cancel{g}/\text{mol}} = 0.167 \text{ moles of N}$$

14.01 g/mol → molar mass of N

$$N_{0.167}O_{0.334}$$

$$\text{moles of O} = \frac{5.34\,\cancel{g}\text{ of O}}{16.00\,\cancel{g}/\text{mol}} = 0.334 \text{ moles of O}$$

16.00 g/mol → molar mass of O

Divide by smallest number of moles:

$$N_{\frac{0.167}{0.167}}O_{\frac{0.334}{0.167}} = NO_2$$

To Determine *Empirical Formula*

1. Determine the mass in grams of each element present, if necessary.

2. Calculate the number of *moles* of each element.

3. Divide each by the smallest number of moles to obtain the *simplest whole number ratio.*

4. If whole numbers are not obtained in step 3, multiply through by the smallest number that will give all whole numbers.

Calculation of Molecular Formula

Example:

A compound has an empirical formula of NO_2. This colorless liquid has a molar mass of 92.0 g/mol. What is the *molecular formula* of this substance?

Solution:

Empirical formula mass of NO_2 = 14.01 + 2(16.00) = 46.01 g/mol

Divide molar mass by empirical formula mass: $\frac{92.0\ g/mol}{46.01\ g/mol} = 2.00$

The molar mass is 2 times the empirical formula mass

therefore the molecular formula is 2 x NO_2 = N_2O_4

A substance can have more than one empirical formula!

$C_3H_4O_3$	Empirical formula mass: 88.06 g/mol
$C_6H_8O_6$	Empirical formula mass : 176.13 g/mol
$C_9H_{12}O_9$	Empirical formula mass : 264.19 g/mol

The **molecule's molar mass** is **required to determine its molecular formula.**

Empirical Formula from % Composition

Example:

A substance has the following percent composition by mass:

60.80 % Na ; 28.60 % B ; 10.60 % H

What is the empirical formula of the substance ?

Solution:

Assume a sample size of 100 grams

This sample will contain 60.80 g of Na, 28.60 grams of B and 10.60 grams H.

Empirical Formula from % Composition (cont'd)

Calculate number of moles of each atom:

	Na	B	H
Number of moles	$\frac{60.80\ g}{22.99\ g/mol}$	$\frac{28.60\ g}{10.81\ g/mol}$	$\frac{10.60\ g}{1.008\ g/mol}$
Molar mass →	= 2.645 mol	= 2.646 mol	= 10.52 mol
Divide by smallest number of moles	$\frac{2.645}{2.645} = 1.000$	$\frac{2.646}{2.645} = 1.000$	$\frac{10.52}{2.645} = 3.977$

Answer: Empirical Formula is $NaBH_4$