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The Mole

Molar Mass, Formulas, % Composition

Dr. Ron Rusay

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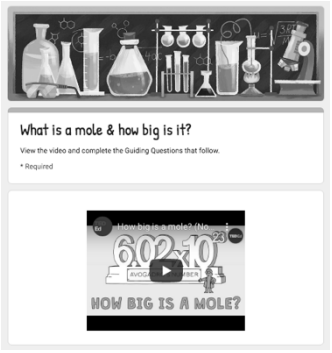


What's My Formula?

Hydrate Solids (Salts + Water)

$MgSO_4 \bullet X\ H_2O(s)$

X = ? [Possibilities: X = 1, 4, 5, 6, 7]

$$MgSO_4 \bullet X\ H_2O(s) \xrightarrow{\text{heat}} MgSO_4(s) + X\ H_2O(g)$$

Mass sample — *Mass after heating* — *Mass sample - Mass after heating*

% H_2O = (*Mass sample - Mass after heating*) / *Mass sample x 100*

An "Epsom" salt sample (A) of 10.00 g was heated and re-heated until it reached a "constant" mass of 5.70 g. What is the % water in the sample?

An "Epsom" salt sample (B) of 10.00 g was heated and re-heated until it reached a "constant" mass of 4.88 g . What is the % water in the sample?

How can you identify (A) and (B) among the 5 choices?

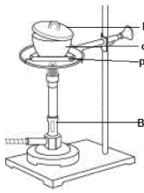
Hydrates

PERCENT WATER IN A HYDRATE

A hydrate is a solid substance, which contains water bound within the crystal lattice of a salt. Water molecules are present in definite proportions in hydrates. Epsom salts, also known as the mineral *epsomite*, is pure magnesium sulfate heptahydrate, $MgSO_4 \cdot 7\ H_2O$. There are seven water molecules present for every one molecule of the salt. Magnesium sulfate heptahydrate can react to produce other hydrates with one, two, three and six molecules of water respectively for each magnesium sulfate. The common name, Epsom salts, comes from the name of a small town in England where in the early 1600s the town's well water was regarded as being curative. Today, it is still regarded as being able to treat splinters, scrapes, insect bites, minor sprains and bruises, to produce lush, healthy lawns, vibrant plants and vegetables as well as a smoother softer skin, and to provide relief from everyday stress. In Shakespeare's 17th century, no one understood the therapeutic mystery of the town's water, and it wasn't until many, many decades later that modern chemistry identified the active mineral component as this particular hydrate.

magnesium sulfate heptahydrate
$MgSO_4 \cdot 7\ H_2O$

First name the "salt" and then count the number of water molecules ("hydrates") & describe with a prefix



Determination of Percent Water in a Hydrate

Unknown number	
Mass, crucible + lid + hydrate sample	
Mass, crucible + lid	
Mass, hydrate sample*	
Mass, crucible + lid + anhydrous product (1st heating)	
Mass, crucible + lid + anhydrous product (2nd heating)	
Mass, crucible + lid + product (3rd heating if necessary)	
Mass, water lost*	
Percent water in hydrate*	

Show the calculations for each of the entries in the Data Table marked with * on the calculations page.

If a weighed hydrate sample is heated and then weighed again, the mass of water released can be determined and the percent water calculated. For example if a 10.00 g sample of a hydrate is found to have a mass of 8.53 g after heating, then the mass of water released can be calculated as follows:

$$10.00\ g - 8.53\ g = 1.47\ g$$

and the percent water is:

$$\frac{1.47\ g}{10.00\ g} = 14.7\ \%$$

Compare the experimental result to a theoretical calculation based on "moles".

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Moles & Mass

How big is a mole?
(Not the animal, the other one.) - Daniel Dulek

https://www.youtube.com/watch?v=TEl4jeETVmg

The Mole

- Definition: The number of carbon atoms in exactly 12 grams of pure ^{12}C. The number equals **6.02×10^{23}** atoms.
- ✓ 1 mole = **6.02×10^{23} units of anything**
- **6.02×10^{23}** "units" of atoms, people, ants, stars, $$$s, etc., etc. = **1 mole**

There are about 7.7 billion people in the world.
(~300,000 being added every day.)
How many moles of people are there?

https://www.worldometers.info/world-population/

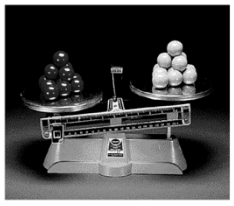
The Mole

There are about 7.7 billion people in the world.
(+300 million since the spring.)
How many moles of people are there?

- **6.02×10^{23}** "units" of atoms, people, ants, stars, $$$s, etc., etc. = **1 mole**

$$\frac{7.7 \times 10^{9} \text{ people}}{6.02 \times 10^{23} \text{ people}} \times 1 \text{ mol} = 1.3 \times 10^{-14} \text{ mol}$$

Counting by Weighing



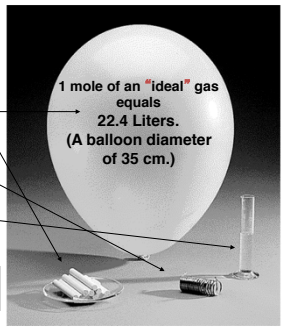
A
12 red marbles @ 7g each = 84g
12 yellow marbles @ 4g each=48g

B
55.85g Fe = 6.022 x 10^{23} atoms Fe
32.07g S = 6.022 x 10^{23} atoms S

Consult the Periodic Table

Relative Masses of 1 Mole

$CaCO_3$
Name?
100.09 g
Oxygen
32.00 g
Copper
63.55 g
Water
18.02 g



What is the volume of 1 mole of water?

Atomic and Molecular Weights
Mass Measurements

- **DEFINITION: mass of ^{12}C = exactly 12 amu.**
- **Using atomic mass units:**
  - **1 amu = 1.66054×10^{-24} g**
  - **1 g = 6.02214×10^{23} amu**

Atomic and Molecular Weights

Los Alamos National Laboratory Chemistry Division

- **Formula Weight a.k.a. Molecular Weight**
- **Formula weights (FW): sum of Atomic Weights (AW) for atoms in formula.**
- **FW (H_2SO_4) = 2AW(H) + AW(S) + 4AW(O)**
- **= 2(1.0 amu) + (32.0 amu) + 4(16.0 amu)**
- **= 98.0 amu**

Los Alamos CHEMISTRY

Atomic and Molecular Weights

- **Molecular weight (MW) is the weight of the molecular formula in amu.**
- **MW of sugar ($C_6H_{12}O_6$) = ?**
- **MW = 6(12.0 amu) + 12(1.0 amu) + 6(16.0 amu)**
- **= 180 amu**

Molar Mass

(amu/mol = grams/mol)

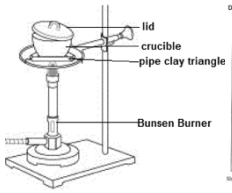
- A substance's **molar mass** is the mass in grams of one mole of the element or compound. (Equals the formula weight: atomic or molecular weight in grams)

Molar Mass CO_2 = ?

C = 12.01 grams per mole (g/mol)
O = 16.00 grams per mole (g/mol)

CO_2 = 44.01 grams per mole (g/mol)
12.01 + 2(16.00) = 44.01 g/mol

Identifying a Hydrate



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Show the calculations for each of the entries in the Data Table marked with * on the calculations page.

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and the percent water is:

$$\frac{1.47\ g}{10.00\ g} = 14.7\ \%$$

Compare the experimental result to a theoretical calculation.

Theoretical Calculation

$$MgSO_4 \bullet X\,H_2O(s) \xrightarrow{heat} MgSO_4(s) + X\,H_2O(g)$$

Mass sample — *Mass after heating* — *Mass sample - Mass after heating*

Calculate the molar mass of magnesium sulfate.

What do you need ?

1) Formula of magnesium sulfate: $MgSO_4$

2) Atomic Weights Mg = 24.31, S = 32.07, O = 16.00

24.31 g/mol + 32.07 g/mol + 4(16.00 g/mol) = **120.38** g/mol

Theoretical Calculation

$$MgSO_4 \bullet X\,H_2O(s) \xrightarrow{heat} MgSO_4(s) + X\,H_2O(g)$$

Mass sample — *Mass after heating* — *Mass sample - Mass after heating*

Calculate the molar mass of magnesium sulfate tetrahydrate.

X = 4

What do you need ?

1) Molar mass of magnesium sulfate, $MgSO_4$ **120.38** g/mol

2) Formula of water: H_2O

3) Molecular Weight H_2O (2 H = 1.0 x 2) + (O = 16.0)
(molar mass)
= 18.0 g/mol

4 mol $_{water}$ x 18.0 g/mol $_{water}$ = **72.0** g

Atomic Weight $MgSO_4 \cdot 4\,H_2O$ = **120.38** + 4(**18.02**)
(molar mass) = 192.44 g/mol

Percent Composition

- Mass percent of an element: (from molar masses)

$$\text{mass \%} = \frac{\text{mass of element in compound}}{\text{mass of compound}} \times 100\%$$

- For iron in iron (III) oxide = ? Fe_2O_3 (Fe = 2x mass Fe)

$$\text{mass \% Fe} = \frac{111.69}{159.69} \times 100\% = 69.94\%$$

Which iron ore would you buy: one high in Fe_2O_3 or one high in Iron (II) oxide? FeO Molar mass = ?

55.84 mass Fe / 71.84 mass FeO x 100 = 77.7%

Formulas: Multiple Proportions

http://chemconnections.org/general/movies/multiple-proportions.MOV

Hydrate: % Water

EPSOM SALT(s)

$MgSO_4 \bullet X\,H_2O(s)$

X = ? [Possibilities: X = 1, 4, 5, 6, 7]

$MgSO_4 \bullet X\,H_2O(s) \rightarrow MgSO_4(s) + X\,H_2O(g)$

Mass sample → *Mass after heating* + *Mass sample - Mass after heating*

% H_2O = (*Mass sample - Mass after heating*) / *Mass sample* x 100

An "Epsom" salt sample (A) of 10.00 g was heated and re-heated until it reached a "constant" mass of 5.70 g. What is the % water in the sample?

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How can you identify (A) and (B) among the 5 choices?

Comparison to Theoretical Calculations

Theoretical Calculation

Percent Composition

Calculate the percent water in magnesium sulfate pentahydrate.

What do you need ?

Atomic Weight $MgSO_4 \cdot 5\,H_2O$ = **120.38** + 5(**18.02**)

(molar mass) = 210.46 g/mol

Calculate the percent water in "Epsom" salt, magnesium sulfate heptahydrate

What do you need ?

Atomic Weight $MgSO_4 \cdot 7H_2O$ = **120.38** + 7(**18.02**)

(molar mass) = 246.49 g/mol

5(**18.02**)/ 210.46 x 100 =	7(**18.02**) / 246.49 x 100 =
42.8%	51.2%

Hydrate: % Water

EPSOM SALT(s)

$MgSO_4 \bullet X\,H_2O(s)$

X = ? [Possibilities: X = 1, 4, 5, 6, 7]

$MgSO_4 \bullet X\,H_2O(s) \rightarrow MgSO_4(s) + X\,H_2O(g)$

Mass sample → *Mass after heating* + *Mass sample - Mass after heating*

% H_2O = (*Mass sample - Mass after heating*) / *Mass sample* x 100

	Hydrate	% H_2O	% MgSO
	$MgSO_4 \cdot H_2O$	13.0	87.0
	$MgSO_4 \cdot 4H_2O$	37.4	62.6
A	$MgSO_4 \cdot 5H_2O$	42.8	57.2
	$MgSO_4 \cdot 6H_2O$	47.3	52.7
B	$MgSO_4 \cdot 7H_2O$	51.2	48.8

Molar / Molar Mass Comparisons

	% Salt	% H O
$MnSO_4 \cdot H_2O$	89.4	10.6
$BaCl_2 \cdot 2\,H_2O$	85.3	14.7
$CaSO_4 \cdot 2\,H_2O$	79.1	20.9
$ZnSO_4 \cdot 7\,H_2O$	56.2	43.8
$MgSO_4 \cdot 7\,H_2O$	48.9	51.1

What is the formula of unknown hydrate #8345?

Unknown Number	8345
Mass, Evaporating Dish + Unknown	61.11 g
Mass, Evaporating Dish** *(enter same value below)*	45.77 g
Mass, Unknown*	
Mass Evaporating Dish + Salt (Product), after heating	55.86 g
Mass Evaporating Dish + Salt (Product), after 2nd heating	55.26 g
Mass, Evaporating Dish** *(same value as above)*	45.77 g
Mass Salt Product (experimental)	
% Salt Product (experimental) Mass Salt Product (experimental) / Mass, Unknown* x 100 =	
% Mass Salt Product *(Theoretical based on Molar Masses calc.)* Choose closest from the 5 possibilities *calculated*	
Identification of Unknown	

Post-Lab Question:

Spectroscopic satellite analysis of the composition of the moon was completed during the Clementine and subsequent NASA missions. The data indicates that water is present on the moon and there may be enough to allow human colonization. The water is tied up in rock (hydrates) and as ice. A notable hydrate for its high water content is Glauber's salt, sodium sulfate decahydrate. If a human were to require the equivalent of 2 liters of water per day, how many kilograms of Glauber's salt would need to be processed per month to meet one person's need. Assume a month is 30 days and that all of the water in the salt is recovered in the process. Glauber's Salt is 56% water by weight.

Conversions: [1.0 L_{H2O}=1.0 kg_{H2O}]; [56%$_{H2O}$=56 kg_{H2O}/100 $kg_{hydrate}$ x 100]

Molar Comparisons of Analgesics

Calculate Moles : Doses (mmol/dose)

Which analgesic has the most biologically active ingredient based on millimoles per dose (*mmol/dose*)?

5.0 g of each would produce the following number of doses:

	Formula	*Doses*	*mmol/dose*
Aspirin	$C_9H_8O_4$	15	*28 mmol*
Ibuprofen	$C_{13}H_{18}O_2$	25	?
Naproxen Sodium	$C_{14}H_{13}O_3Na$	22.7	?
Acetaminophen	$C_8H_9NO_2$	5	?

Molar Mass Aspirin = 180.1 g/mol
5.0 g */ 180.1 g/mol = 0.028 mol = 28 mmol*

https://forms.gle/fkssFiStkUXCY7c36

Lab Lesson & Post Lab Questions

Colonizing the Moon
&
Therapeutic Analgesic Doses
grams vs. mmol

https://forms.gle/rn5mD44KmfcDbDSR7