Amount of Substance – Mole Calculations

Mass Calculations

1. Relative Atomic Mass (RAM)

a. Define RAM

b. Calculate RAM from isotopes and abundances

c. Interpret mass spectra to find isotopes and abundances

2. Relative Formula Mass (Mr)

a. Calculate Mr for a compound

b. Calculate % mass for each element within a compound

3. Mole and mass

a. Define the mole (Mr in grams)

b. Interconvert mole and mass

c. Derive mole = mass / Mr

4. Avagadro Constant

a. Redefine the mole (Avagadro constant)

b. Calculate numbers of atoms and molecules from mass

5. Calculations involving chemical reactions

a. Empirical formula and molecular formula

b. Mass calculations

c. Percentage Yield

Mass Calculations

1. Relative Atomic Mass (RAM)

*interconvert **mass** and **amount***

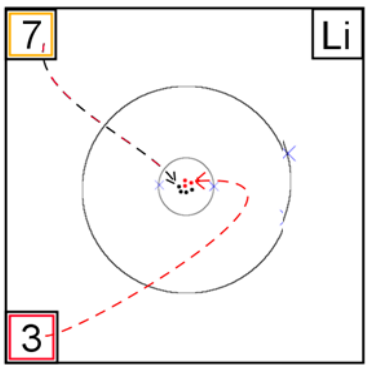
*need **mass of each atom***

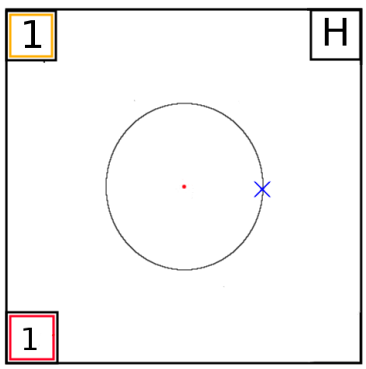
We are learning to:

a. ***identify the slight discrepancy between mass number and actual mass***
b. ***explain this in terms of binding energy***
c. ***identify the presence of isotopes as having a far more significant effect upon mass***
d. ***calculate the average mass across all isotopes***

...by which time we will have defined Relative Atomic Mass (RAM)

a. identify the slight discrepancy between mass number and actual mass



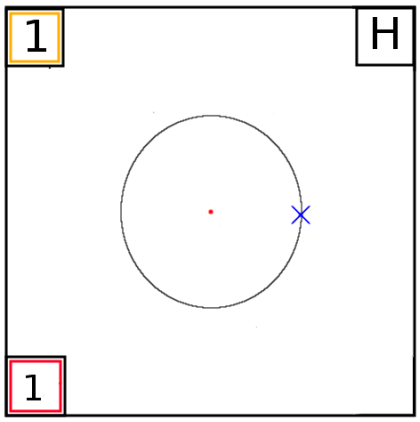


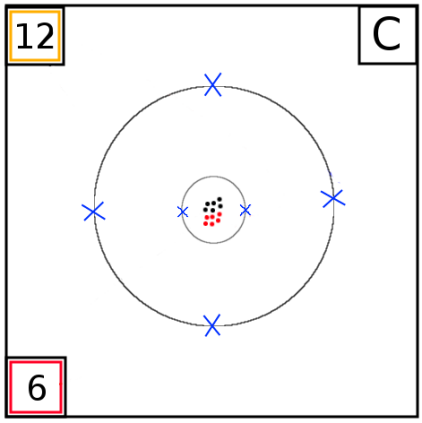
Would expect there to be a factor of x7 between the masses of these two atoms, but this isn't quite true, because the mass of protons and neutrons varies slightly from one atom to another.

Why does the mass of protons and neutrons vary?

Protons in the nucleus repel each other – they are all positively charged and like charges repel. To keep them stuck together there must be a force which binds them together. This binding energy causes a reduction in the mass of the nucleus, as some of the mass is turned into energy.

Therefore, generally the larger the atom, the smaller the average mass of the protons and neutrons, because more mass is converted into binding energy.





For example, if we compare carbon-12 and hydrogen, and set the *carbon* value as exactly 12 (and this *is* what we do; the carbon-12 atom is used as a reference), then we would expect the mass of the hydrogen to be 1, but...due to, in this case, the lack of binding energy, in fact its mass relative to the carbon is 1.007825.

atom	mass number	mass relative to ^{12}C
^{1}H	1	
^{12}C	12	
^{56}Fe	56	

Summary

- **MASS OF PROTONS AND NEUTRONS IS *NOT THE SAME* IN ALL ATOMS.**
- **THE ACTUAL MASS OF ATOMS *VARIES SLIGHTLY* FROM THE MASS NUMBER**

Let's choose another example, to see how this builds up throughout the periodic table. We could do a similar comparison for iron-56 and carbon, and we find that the mass is not 56, but slightly less due to more binding energy, and is in fact 55.934934

1.007825 write as 1.008

12.00000 (by definition) write as 12.000

55.934934 write as 55.934

As you can see, these differences are rather small, and certainly cannot account for this;

"Relative atomic mass of copper is 63.55"

Such big deviations from whole numbers are not due to the slight change in mass of the protons and neutrons, they are caused by isotopes; atoms with the same number of protons, but a different number of neturons.

Isotopes

"Relative atomic mass of copper is 63.55"

Isotope	Mass	%
^{63}Cu	62.93	69
^{65}Cu	64.93	31

If we put a sample of copper in a mass spectrometer, we get the following result:

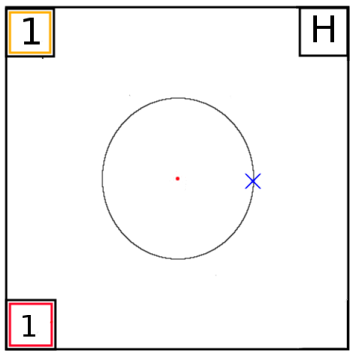
We can work out a weighted average across all isotopes:

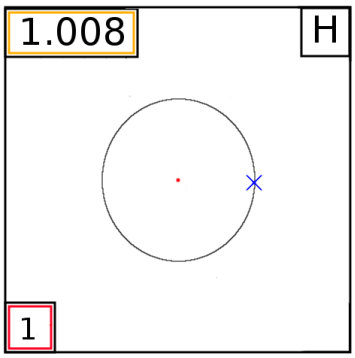
$$62.93 \times 69\% \quad + \quad 64.93 \times 31\% \quad = \quad \mathbf{63.55}$$

Summary

- **WEIGHTED AVERAGE ACROSS ALL ISOTOPES**

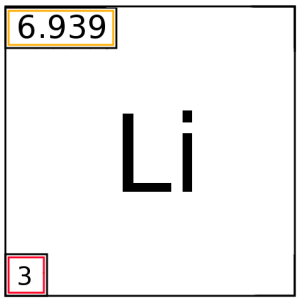
summary: the weighted average across all isotopes gives us a useful value for the mass of copper atoms. If we have an amount of copper, it will include both isotopes and we must account for this when interconverting mass and numbers of atoms.

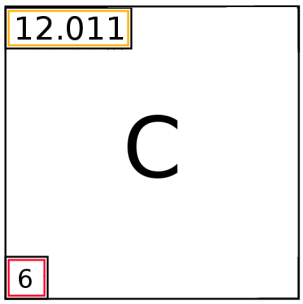


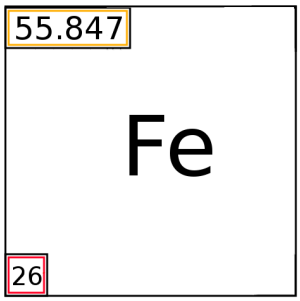


RELATIVE ATOMIC MASS

to ^{12}C averaged across all isotopes







Assessment

1. Cobalt exists only as the ^{59}Co isotope. What would you expect the relative atomic mass of cobalt to be?

A.	slightly higher than 59 due to more binding energy than ^{12}C	B.	slightly lower than 59 due to more binding energy than ^{12}C
C.	slightly lower than 59 due to less binding energy than ^{12}C	D.	slightly higher than 59 due to less binding energy than ^{12}C

2. If approximately 20% of boron is the ^{10}B isotope and 80% is the ^{11}B isotope, estimate the relative atomic mass of boron

A.	(0.2 x 10) + (0.8 x 11) =	**10.2**	B.	(0.2 x 11) + (0.8 x 10) =	**10.2**
C.	(0.2 x 10) + (0.8 x 11) =	**10.8**	D.	(0.2 x 11) + (0.8 x 10) =	**10.8**

Answers 1. B, 2. C

Amount of Substance – Mole Calculations

Mass Calculations

1. Relative Atomic Mass (RAM)

2. Relative Formula Mass (Mr)

a. Calculate Mr for a compound

b. Calculate % mass for each element within a compound

3. Mole and mass

4. Avagadro Constant

5. Calculations involving chemical reactions

What is the relative formula mass of $MgCl_2$?

We can look at the periodic table to find the relative atomic mass for each element, but what if we wanted to find the relative mass of a compound? Easy! Add up the relative atomic massess of each of the elements.

For example; what is the relative formula mass of $MgCl_2$?

RAM (Mg) 24.312

RAM (Cl) 35.453

for $MgCl_2$ 24.312
+ 2 x 35.453
= 95.218

Using the notation Mr to mean either relative atomic mass or relative formula mass, we have:

M_r (Mg) = 24.312

M_r (Cl) = 35.453

M_r ($MgCl_2$) = 95.218

Mass Calculations

2. Relative Formula Mass (Mr)

b. Calculate % mass for each element within a compound

For the compound MgO, what percentage of its mass is made up of Mg atoms, and what percentage is made up of O atoms?

Mr(Mg) = 24.312 Mr (O) = 16.000

therefore Mr (MgO) is 24.312 + 16.000 = **40.312**

24.312 / 40.312 = 60.3% mass due to Mg

16.000 / 40.312 = 39.7% mass due to O

It's 50:50 isn't it? MgO, 1:1, same number of each type of atom.

This is *true* in terms of number of atoms, but ***not*** int terms of mass because the Mg and O atoms have different weights. Specifically,

Mr(Mg) is 24.312

Mr (O) is 16.000

therefore Mr (MgO) is 24.312 + 16.000

= **40.312**

Of this 40.312, 24.312 comes from Mg and 16.000 comes from oxygen.

In percentage terms, 24.312 / 40.312 = 60.3% of the mass comes from Mg atoms

16.000 / 40.312 = 39.7% of the mass comes from oxygen atoms.

Amount of Substance – Mole Calculations

Mass Calculations 2. Relative Formula Mass (Mr)

Assessment

1. Match each molecule to its M_r using these relative atomic masses:

$M_r(H) = 1$, $M_r(O) = 16$, $M_r(C) = 12$

CH_4	32
H_2O	26
O_2	16
C_2H_2	18

2. Calcium carbonate, $CaCO_3$, has M_r of 100. Using the following relative atomic masses, match the percentage mass of each element within calcium carbonate.

$M_r(Ca) = 40$, $M_r(C) = 12$, $M_r(O) = 16$

calcium	12%
oxygen	40%
carbon	48%

Amount of Substance – Mole Calculations

Mass Calculations

1. Relative Atomic Mass (RAM)

2. Relative Formula Mass (Mr)

3. Mole and mass

a. Define the mole

b. Interconvert mole and mass

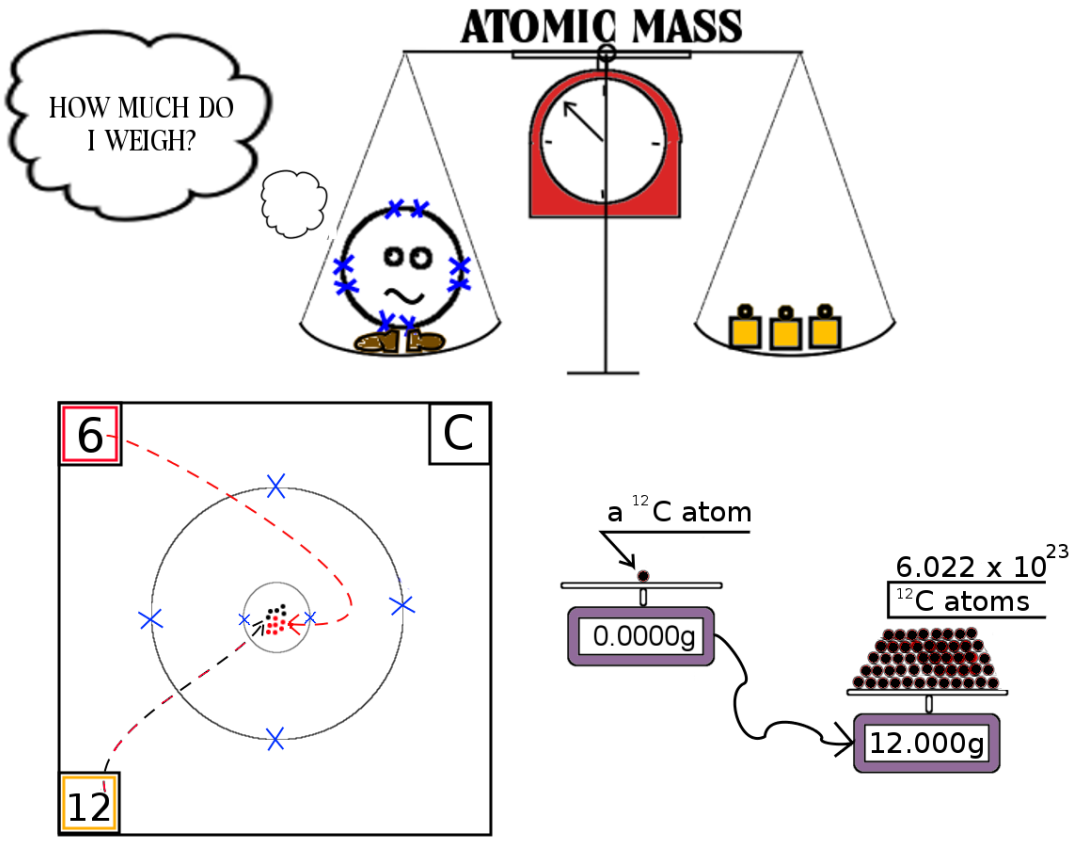
c. Derive mole = mass / Mr

4. Avagadro Constant

5. Calculations involving chemical reactions

The overall aim of this topic on mass calculations is to interconvert mass and amount, i.e. number of atoms, but so far we haven't mentioned any masses.

Let's put our carbon-12 atoms on the scales and see how much it weights...



...hmmm not much. So let's keep on adding atoms until the mass in grams is the same as the relative mass. The Mr of carbon-12, is of course, exactly 12.

This number is given a name, "the mole"; but it is just a number and has a fixed value of 6.022 x1023.

In other words we had to put 6.022 x 1023 carbon-12 atoms on the scale to have a 'mole of carbon12 atoms".

So we can define a mole as the amount of substance when the Mr is given in a unit of grams.

Now we are ready to interconvert mass and amount in mol.

Amount of Substance – Mole Calculations

Mass Calculations

3. Mole and mass b. Interconvert mole and mass

Example 1: ***If I have 1 mol of Cu, what mass has this?***

Mr (Cu) is 63.55

therefore, **mass of 1 mol of Cu is 63.55g**

Example 2: ***What is the mass of 1 mol of CuO?***

Mr (CuO) = 63.55 + 16.00 = 79.55

therefore, **mass of 1 mole of CuO is 79.55g**

We can think of this as a ratio

mole	:	mass
1	:	Mr

Example 3: ***What is the mass of 0.23mol of Cu?***

	mole	:	mass
	1	:	Mr
Cu	1	:	63.55g
	0.23	:	63.55 x 0.23
			= **14.62g**

And we can also work backwords in these calculations

Example 4: ***I have 10.6g of Cu, how many moles of copper is this?***

	mole	:	mass
	1	:	Mr
Cu	1	:	63.55g
	1/63.55	:	1g
	0.167	:	10.6g

Amount of Substance – Mole Calculations

Mass Calculations

3. Mole and mass

c. Derive mole = mass / Mr

How do I get the mass from the number of moles?

multiply by Mr

therefore **mass = mol x Mr**

Mr as the subject

What are the units of Mr?

grams per mol

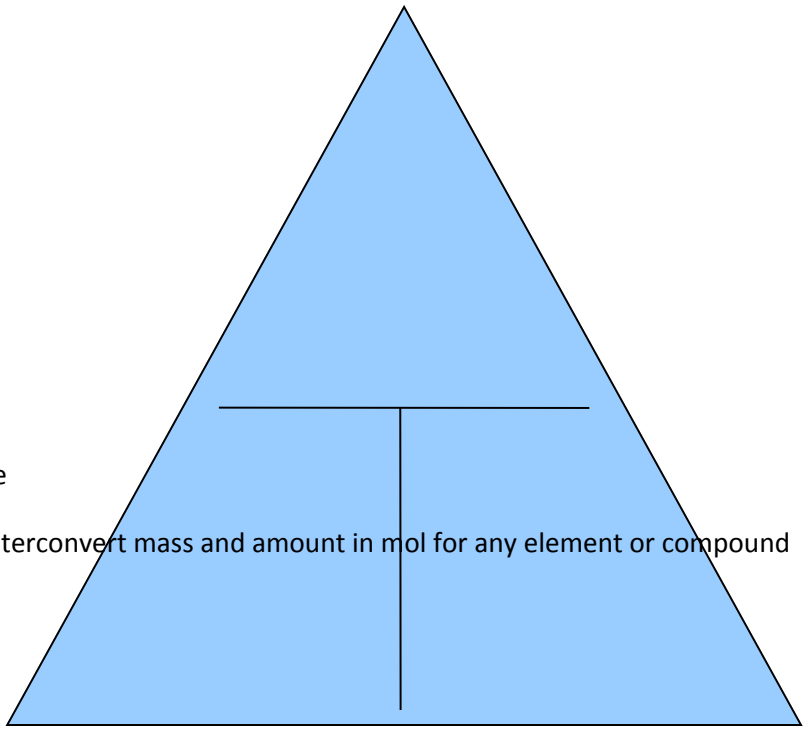
therefore **Mr = mass /mol**

Or, as a formula;

Amount in mol = mass / Mr

mass = mol x Mr

Or in a triangle



now we can interconvert mass and amount in mol for any element or compound

Amount of Substance – Mole Calculations

Mass Calculations 3. Mole and mass

Assessment

1. Choose **a** or **b** then **i** or **ii** $M_r(Al) = 26.9$, $M_r(Co) = 58.9$

1 mol of Al atoms weighs	*a) more than*	1 mol of Co atoms because each Al atom is	*i) more heavy*	than each Co atom.
	b) less than		ii) *less heavy*	

Answers: 1 b) ii)

2. Match the amounts to the masses $M_r(CO_2) = 44$, $M_r(CaCO_3) = 100$

amount		mass
0.25 mol of CO_2		110g
0.25 mol of $CaCO_3$		25g
1.1 mol of CO_2		11g
1.1 mol of $CaCO_3$		55g

Amount of Substance – Mole Calculations

Mass Calculations

1. Relative Atomic Mass (RAM)

2. Relative Formula Mass (Mr)

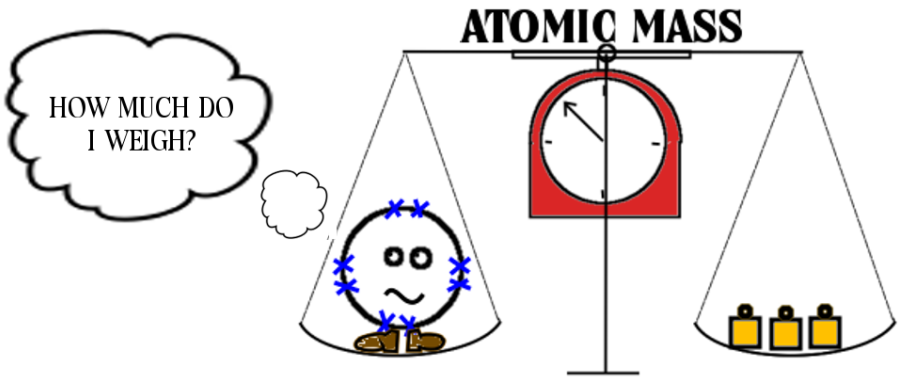
3. Mole and mass

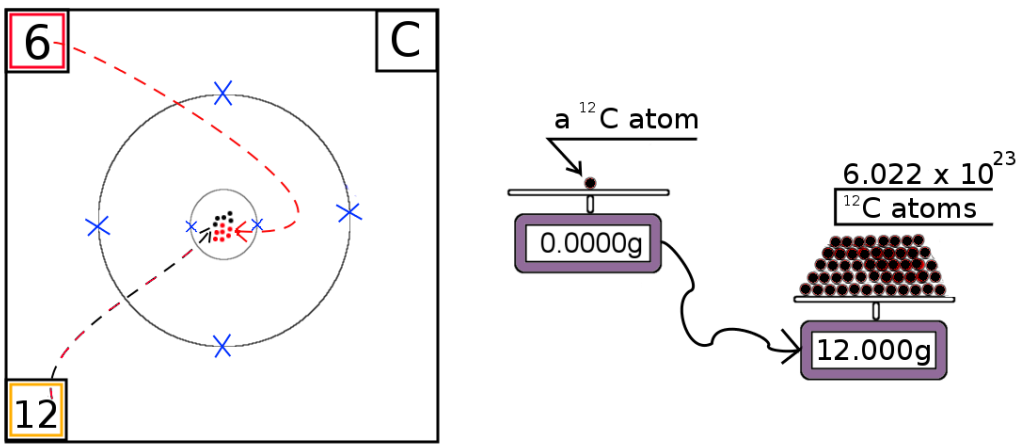
4. Avagadro Constant

a. The mole and the Avagadro Constant

b. Calculate numbers of atoms and molecules from mass

5. Calculations involving chemical reactions





Amount of Substance – Mole Calculations

Mass Calculations

4. Avagadro Constant

b. Calculate numbers of atoms and molecules from mass

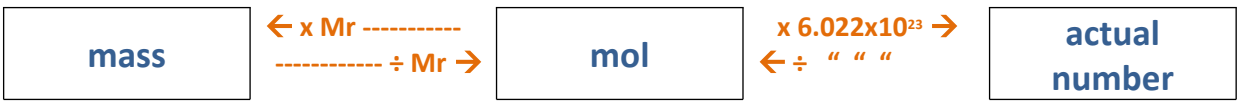
Amount of Substance – Mole Calculations

Mass Calculations

4. Avagadro Constant

b. Calculate numbers of atoms and molecules from mass

Example 4: *I have 10.6g of Cu, how many atoms of copper is this?*



Amount of Substance – Mole Calculations

Mass Calculations

Example 5: *I have 0.821g of $MgCl_2$, how many chloride ions are in this?*

mass	← x Mr ---------- / ---------- ÷ Mr →	mol	x 6.022x10²³ → / ← ÷ " " "	actual number
0.821g	← x Mr ---------- / *÷ Mr (95.218)* →	*0.821/95.218*	*x 6.022x10²³* → / ← ÷ " " "	**5.192×10^{21}**

5.192×10^{21} what?

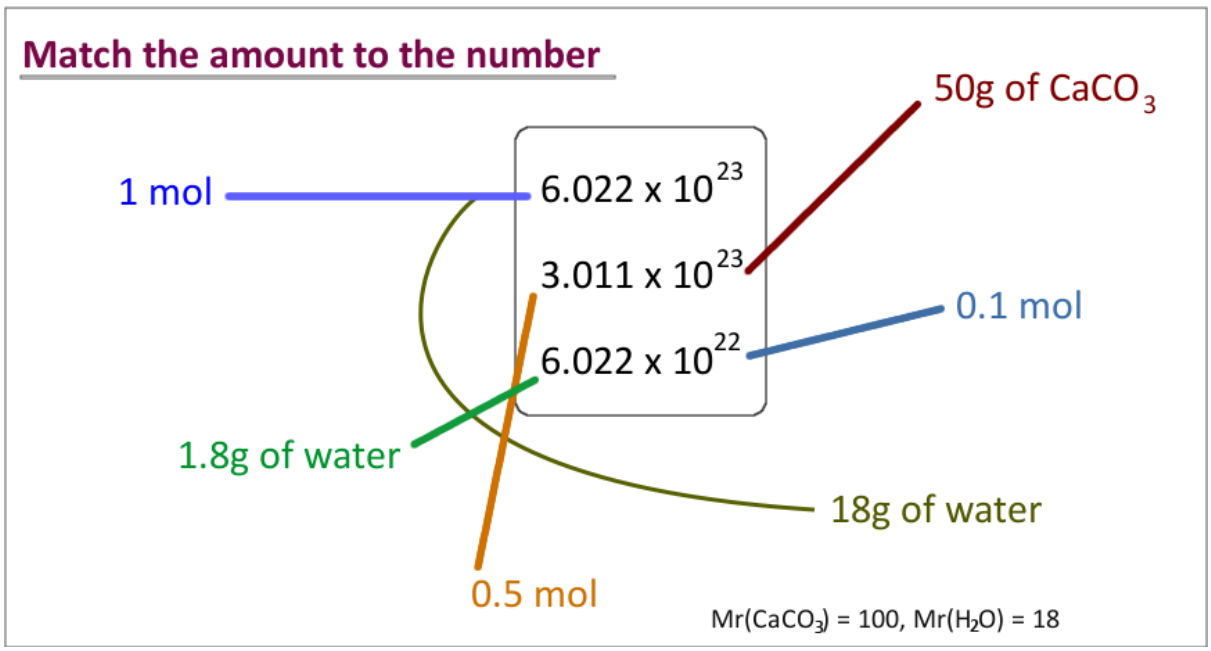
units of $MgCl_2$

each containing 2 Cl- ions

therefore $2 \times 5.192 \times 10^{21}$

= 1.038x 10²² Cl- ions

mass	---------- ÷ Mr →	mol	x 6.022x10²³ →	actual number



Amount of Substance – Mole Calculations

Mass Calculations

1. Relative Atomic Mass (RAM)

2. Relative Formula Mass (Mr)

3. Mole and mass

4. Avagadro Constant

5. Calculations involving chemical reactions

a. Empirical formula and molecular formula

b. Mass calculations

c. Percentage Yield