Simple Step-by-Step Guides to Solving Chemistry Problems

The MOLE

Nigel Freestone
www.chemtextbook.com

The MOLE

The Mole is simply a number. Just as the term dozen refers to the number (12) twelve and a score to the number (20) twenty, the mole refers to the number 6.023×10^{23}. Thus 12 eggs is a dozen of eggs, 20 eggs is a score of eggs and 6.023×10^{23} eggs is a mole of eggs. Commonly referred to as Avogadro's constant, 6.023×10^{23} is the number of atoms found in exactly 12 grams of carbon-12. Carbon-12 is used as the standard from which atomic masses are measured: its mass number is 12 by definition. Since 12 g of carbon contains one mole of carbon atoms, the mass of one mole of any element is equal to its relative atomic mass in grams. Magnesium has relative atomic mass of 24. Therefore, one mole of magnesium has a mass of 24 g. Thus 24 g of magnesium contains 6.02×10^{23} magnesium atoms and the mass of one atom of magnesium = $24/(6.02 \times 10^{23}) = 3.987 \times 10^{-23}$ g. Similarly, the mass of one mole of lithium atoms is 7g, 27 g of aluminium contains one mole of atoms and the mass of one mole of calcium, is 40g etc. You can also work with fractions (or multiples) of moles:

Mole/Mass Relationship Examples Using Magnesium

Moles Magnesium	***Number of Magnesium Atoms***	***Mass of Magnesium***
0.25	1.505×10^{23}	6 g
0.5	3.01×10^{23}	12 g
1	6.02×10^{23}	24 g
2	1.204×10^{24}	48 g
10	6.02×10^{24}	240 g
50	3.01×10^{25}	1200 g

Some elements exist as molecules rather than atoms. The following elements all exist as diatomic molecules: hydrogen (H_2), nitrogen (N_2), oxygen (O_2) and the halogens (F_2, Cl_2, Br_2, I_2).. Hydrogen has a relative atomic mass of 1. Therefore, the relative formula mass of (M_r) of $H_2 = (2 \times 1) = 2$. Therefore, one mole of hydrogen molecules will have a mass of 2g and will cont 6.02×10^{23} molecules of hydrogen. Oxygen has a relative atomic mass of 16. Thus one mole of oxygen gas (O_2) has a mass of 32 g and 6.02×10^{23} molecules of nitrogen gas (N_2) have a mass of 28g.

The concept of a mole is equally applicable to compounds as well as elements. One mole of a compound is its relative formula mass (M_r) in grams. To avoid any ambiguity it is convenient to use the term **formula unit**. Formula unit refers to the smallest repeating unit of a substance and is the chemical formula normally used for the substance. For instance, the formula unit of graphite is an atom of carbon (C). Similarly, the formula unit of oxygen gas is an oxygen molecule (O_2); NaCl is the formula unit for the ionic compound sodium chloride and the formula unit for silicon dioxide is SiO_2.

Equimolar amounts of substances contain the same number of formula units. Thus 0.5 moles any substance will contain the same number of formula units (particles), ie $0.5 \times 6.02 \times 10^{23} = 3.01 \times 10^{23}$.

The idea of the **mole** links the **mass of a substance** to the **number of formula units** (particles) it contains. The mass of one mole of an element or compound is referred to as its **molar mass**, which is its **relative atomic mass (A_r)** or **relative formula mass (M_r)** in grams.

Molar Mass (M_r) = Relative Formula Mass in grams (g mol^{-1})

If you have *m* grams of a substance which has a molar mass of M_r g mol^{-1}, then the amount of a substance in moles, *n*, is given by: -

Number of moles = Mass (g) / Molar Mass (g mol^{-1})

Number of formula units (particles) = Number of moles x 6.23 x 10^{23}

Number of moles = mass (g) / M_r (g mol^{-1})

Thus, if you know the values of any two of n, m or M_r you can calculate the third using the equations above.

Water has a relative formula mass of 18. Thus:

- one mole of water has a mass of 18 g
- 18 g of water contains 6.02 x 10^{23} formula units of water
- 0.5 moles of water has a mass of 9g
- one molecule of water has a mass of 18/(6.02 x 10^{23}) = 2.99 x 10^{-23} g

Example 1: *Determine the mass of one mole of O_2?*

Answer
Relative formula mass of O_2 = (2 x 16) = 32
Mass of one mole, ie molar mass = M_r in g
Molar Mass, M_r [O_2] = **32 g mol^{-1}**

Example 2: *What is the mass of 0.05 moles of ammonium sulfate?*

Answer
Relative formula mass of $(NH_4)_2SO_4$ = (2 x 14) + (8 x 1) + 32 + (4 x 16) = 132
Mass of one mole, ie molar mass = M_r in g
Molar Mass, M_r [$(NH_4)_2SO_4$] = 132 g mol^{-1}
Therefore, 0.05 moles of ammonium sulfate has a mass of 132 x 0.05 = **6.6 g**

Example 3: *How many moles of substance are present in 0.250 g of calcium carbonate?*

Answer
Relative formula mass of $CaCO_3$ = 40 + 12 + (3 x 16) =100
Mass of one mole, ie molar mass = M_r in g
Molar Mass, M_r [$CaCO_3$] = 100g mol^{-1}
So the number of moles of $CaCO_3$ in 0.250 g = mass/M_r = 0.250/100 = **2.5 x 10^{-3} moles**

Example 4: *How many formula units are present in 9 g of KNO_3?*

Answer
Relative formula mass of KNO_3 = 39 + 14 + (3 x16) = 101
Mass of one mole, ie molar mass = M_r in g
Molar Mass, Mr (KNO_3) = 101g
Number of moles of KNO_3 in 9g = mass/M_r = 9/101 = 0.09
One mole of a substance contains 6.02 x 10^{23} formula unit particles

Therefore, the number of formula particle units in 0.09 moles = number of moles x 6.02 x 10^{23} = 0.09 x 6.02 x 10^{23} = **45.41 x 10^{22}**

Example 5: *An average person's respiration generates approximately 37.5 g of carbon dioxide per hour. How many molecules are in 37.5 g of carbon dioxide (CO_2)?*

Answer
M_r [CO_2] = 44 g mol^{-1}
Number of moles of CO_2 in 37.5 g = mass/M_r = 37.5/44 = 0.85 moles
One mole of CO_2 contains 6.02 x 10^{23} molecules of CO_2
Therefore, number of molecules of CO_2 in 0.85 moles = number of moles x 6.02 x 10^{23} = 0.85 x 6.02 x 10^{23} = **5.12 x 10^{23}**

Example 6: *What mass of ozone (O_3) contains 3.67 x 10^{22} molecules of O_3?*

Answer
M_r [O_3] = 48 g mol^{-1}
Thus 48 g of O_3 contains 6.02 x 10^{23} molecules of ozone
One molecule of O_3 will have a mass of 48 / (6.02 x 10^{23})
Therefore, 3.67 x 10^{22} molecules of O_3 will have a mass of 48 / (6.02 x 10^{23}) x 3.67 x 10^{22} = 2.93 g

Example 7: Complete the following table relating to calcium carbonate

Substance	M_r	Number of moles (n)	Mass in grams (m)	Number of particles
Carbon dioxide, CO_2	i)	1.5	vii)	x)
Nitrogen, N_2	ii)	v)	7	xi)
Sulfur Dioxide, SO_2	iii)	0.15	viii)	xii)
Ethanol, C_2H_5OH	iv)	vi)	ix)	1.2 x 10^{21}

Answers:

Substance	M_r	Number of moles (n)	Mass in grams (m)	Number of particles
Carbon dioxide, CO_2	44	1.5	66	9.03 x 10^{23}
Nitrogen, N_2	28	0.25	7	1.505 x 10^{23}
Sulfur Dioxide, SO_2	64	0.15	9.6	9.03 x 10^{22}
Ethanol, C_2H_5OH	46	0.002	0/09	1.2 x 10^{21}

M_r values
i) M_r [CO_2] = 12 + (2 x 16) = 44
ii) M_r [N_2] = (2 x 14) = 28
iii) M_r [SO_2] = 32 + (2 x 16) = 64
iv) M_r [C_2H_5OH] = (2 x 12) + (5 x 1) + 16 + 1 = 46

Number of moles
Number of formula units (particles) = Number of moles x 6.23 x 10^{23}

v) Number of moles in 7g N_2 = mass/M_r = 7/28 = 0.25
vi) Number of moles in 1.2 x 10^{21} particles of C_2H_5OH = number of particles/6.02 x 10^{23} = 1.2 x 1021/6.02 x 10^{23} = 0.002

Mass in grams
Mass (g) = Number of moles x M_r
vii) Mass of 1.5 moles of CO_2 = number of moles x M_r = 1.5 x 44 = 66
viii) Mass of 0.15 moles SO_2 = number of moles x M_r =0.15 x 64 = 9.6g

Number of particles
Number of formula units (particles) = Number of moles x 6.23 x 10^{23}
x) Number of particles in 1.5 moles CO_2 = number of moles x 6.02 x 10^{23} = 9.03 x 10^{23}
xi) Number of moles in 7g N_2 = mass/M_r = 7/28 = 0.25
Number of particles in 0.25 moles CO_2 = number of moles x 6.02 x 10^{23} = 0.25 x 6.02 x 10^{23} =1.505 x 10^{23}
xii) Number of particles in 0.15 moles of SO_2 = number of moles x 6.02 x 10^{23} = 9.03 x 10^{22}

In summary, a mole always contains the same number of formula units (particles) regardless of the substance. But, the mass of a mole differs from substance to substance, and is the relative formula mass expressed in grams. Really the mole is just a collective term like the dozen. A dozen elephants weigh more than a dozen mice, but we have the same number of each.

It is very important to state the particles you are referring to when talking about moles. A mole of oxygen could refer to a mole of oxygen atoms or to a mole of gas, which is diatomic (O_2). So a mole of oxygen atoms (O) will have a mass of 16g, while a mole of oxygen gas (O_2) has a mass of 16 x 2 = 32g.

The concept of the mole is useful because the size and mass of atoms are so small; hence Avogadro's number is so large.

PRACTICE PROBLEMS

Exercise 1

Calculate the molar masses (M_r) of the following:-

a) *Chlorine, Cl_2*

b) *Sulfur dioxide, SO_2*

c) *Zinc nitrate, $Zn(NO_3)_2$*

d) *Magnesium carbonate, $MgCO_3$*

e) *Oxalic acid, $C_2H_4O_2$*

f) *Calcium chloride, $CaCl_2$*

g) *Aluminum sulphate, $Al_2(SO_4)_3$*

h) *Sulfuric acid, H_2SO_4*

i) Potassium mangante (VII), $KMnO_4$

j) Sodium chromate (VI), Na_2CrO_4

Exercise 2

How many moles of substance are present in the following?

a) 5.30 g of sodium carbonate, Na_2CO_3

b) 0.35 g of zinc nitrate, $Zn(NO_3)_2$

c) 0.008 g of sodium hydroxide, NaOH

d) 1.25 g of calcium carbonate, $CaCO_3$

e) 3.5 g of benzene, C_6H_6

f) 12 g of glucose, $C_6H_{12}O_6$

g) 1g of uranium dioxide, UO_2

h) 0.3 g aluminium sulphate, $Al_2(SO_4)_3$

i) 1.2 g iron (III) oxide, Fe_2O_3

j) 3.4 g sulphur trioxide, SO_3

Exercise 3

How many formula units are present in the following?

a) 0.25 moles of Cl_2

b) 5 moles of CO_2

c) 10g of $CaCO_3$

d) 2.45×10^{-3} moles of NH_3

e) 0.34 kg of Fe_3O_4

f) 2.56 moles of C_6H_6

g) 1×10^{-6} g of Au

h) 0.12 moles of $CuSO_4$

i) 1 tonne of N_2

j) 4.45×10^{-6} moles of $(NH_4)_2CO_3$

Exercise 4: *Determine the mass of the following:*

a) 2 moles of carbon dioxide, CO_2

b) 0.01 moles of nitrogen dioxide, NO_2

c) 1 x 10^{-5} moles of benzene, C_6H_6

d) 2.03 x 10^{-3} moles of uranium dioxide, UO_2

e) 1.12 moles of sulphuric acid, H_2SO_4

f) 3 x 10^{-4} moles of calcium carbonate, $CaCO_3$

g) 1.2 moles of ethane, C_2H_4

h) 0.5 moles ethanoic acid, CH_3COOH

i) 1.25 x 10^{-3} moles sodium hydroxide, NaOH

j) 0.025 moles potassium dichromate, $K_2Cr_2O_7$

Practice Problems Mole Answers

Exercise 1: *Calculate the molar masses (M_r) of the following:-*

Molar Mass = Relative Formula Mass (M_r) in g

Answers

a) Cl_2 = (35.5 x 2) = **71 g**

b) SO_2 = 32 + (16 x 2) = **64 g**

c) $Zn(NO_3)_2$ = 65 + {2 x (14 + (16 x 3))} = **189 g**

d) $MgCO_3$ = 24 + 12 + (16 x 3) = **84 g**

e) $C_2H_4O_2$ = (2 x 2) + (1 x4) + (16 x 2) = **60 g**

f) $CaCl_2$ = 40 + (35.5 x 2) = **111g**

g) $Al_2(SO_4)_3$ = (27 x 2) + {3 x (32 + (16 x 4))}= **342 g**

h) H_2SO_4 = {(1 x2) + 32 + (16 x 4)} = **98 g**

i) $KMnO_4$ = {39 +55 + (16 x 4)} = **158 g**

j) Na_2CrO_4 = {(23 x2) + 52 + (16 x 4)} = **162 g**

Exercise 2: *How many moles of substance are present in the following?*

Number of Moles = Mass/M_r

a) 5.30 g of sodium carbonate, Na_2CO_3

Answer
M_r [$Na(CO_3)_2$] = 106 g mol^{-1}
Number of moles in 5.3 g of sodium carbonate = mass/M_r = 5.3/106 = **0.05**

b) 0.35 g of zinc nitrate, $Zn(NO_3)_2$

Answer
M_r [$Zn(NO_3)_2$] = 189 g mol^{-1}
Number of moles in 0.35 g of zinc nitrate = mass/M_r = 0.35/189 = **1.85×10^{-3}**

c) 0.008 g of sodium hydroxide, NaOH

Answer
M_r [NaOH] = 40 g mol^{-1}
Number of moles in 0.008g of sodium hydroxide = mass/M_r = 0.008/40 = **2×10^{-4}**

d) *1.25 g of calcium carbonate, $CaCO_3$*

Answer
M_r [$CaCO_3$] = 100 g mol^{-1}
Number of moles in 1.25g of calcium carbonate = mass/M_r = 1.25/100 = **0.0125**

e) *3.5 g of benzene, C_6H_6*

Answer
M_r [C_6H_6] = 78 g mol^{-1}
Number of moles of benzene in 3.5g = mass/M_r = 3.5/78 = **0.045**

f) *12 g of glucose, $C_6H_{12}O_6$*

Answer
M_r [$C_6H_{12}O_6$] = 180 g mol^{-1}
Number of moles in 12g of glucose = mass/M_r = 12/180 = **0.067**

g) *1g of uranium dioxide, UO_2*

Answer
M_r [UO_2] = 270 g mol^{-1}
Number of moles in 1g of uranium dioxide = mass/M_r = 1/270 = **3.7×10^{-3}**

h) *0.3 g aluminium sulphate, $Al_2(SO_4)_3$*

Answer
M_r [$Al_2(SO_4)_3$] = 342 g mol^{-1}
Number of moles in 0.3g aluminium sulphate = mass/M_r = 0.3/342 = **8.77×10^{-4}**

i) *1.2 g iron (III) oxide, Fe_2O_3*

Answer
M_r [Fe_2O_3] = 160 g mol^{-1}
Number of moles in 1.2 g iron (III) oxide = mass/M_r = 1.2/160 = **7.5×10^{-3}**

j) *3.4 g sulphur trioxide, SO_3*

Answer
M_r [SO_3] = 80 g mol^{-1}
Number of moles in 3.4 g sulphur trioxide, SO_3 = mass/M_r =3.4 /80 = **0.0425**

Exercise 3 *How many formula units are present in the following?*

Number of formula units = Number of moles x 6.02×10^{23}

a) *0.25 moles of Cl_2*

Answer
Number of molecules of Cl_2 in 0.25 moles = 0.25 x 6.02 x 10^{23} = **1.51 x 10^{23}**

b) *5 moles of CO_2*

Answer
Number of molecules of CO_2 in 5 moles = 5 x 6.02 x 10^{23} = **3.01 x 10^{24}**

c) *10g of $CaCO_3$*

Answer
M_r [$CaCO_3$] = 100
Number of moles in10g of $CaCO_3$ = mass/Mr = 10/100 = 0.1
Number of formula units in 10 g of $CaCO_3$ = 0.1 x 6.02 x 10^{23} = **6.02 x 10^{22}**

d) *2.45 x 10^{-3} moles of NH_3*

Answer
Number of formula units (molecules) of NH_3 in 2.45 x 10^{-3} moles = 2.45 x 10^{-3} x 6.02 x 10^{23} = **1.48 x 10^{21}**

e) *0.34 kg of Fe_3O_4*

Answer
M_r [Fe_3O_4] = 232
Number of moles of Fe_3O_4 in 340 g (0.34 kg) = mass/M_r = 340/232 = 1.47
Number of formula units in 0.24 kg of Fe_3O_4 = 1.47 x 6.02 x 10^{23} = **8.85 x 10^{23}**

f) *2.56 moles of C_6H_6*

Answer
Number of particles (molecules) in 2.56 moles of C_6H_6 = 2.56 x 6.02 x 10^{23} = **1.54 x 10^{24}**

g) *1 x 10^{-6} g of Au*

Answer
Number of moles of Au in 1 x 10^{-6} g = 1 x 10^{-6}/197 = 5.08 x 10^{-9}
Number of atoms of Au in 1 x 10^{-6} g = 5.08 x 10^{-9} x 6.02 x 10^{23} = **3.06 x 10^{15}**

h) *0.12 moles of $CuSO_4$*

Answer
Number of formula units of $CuSO_4$ in 0.12 moles = 0.12 x 6.02 x 10^{23} = **7.22 x 10^{22}**

i) *1 tonne of N_2*

Answer
M_r [N_2] = 28
Number of moles of N_2 in 1000 g (1 tonne) = 1000/28 = 35.7
Number of formula units in 1 tonne N_2 = 35.7 x 6.02 x 10^{23} = **2.15 x 10^{25}**

j) *4.45 x 10^{-6} moles of $(NH_4)_2CO_3$*

Answer
Number of formula units in 4.45 x 10^{-6} moles of $(NH_4)_2CO_3$ =4.45 x 10^{-6} x 6.02 x 10^{23} = **2.68 x 10^{18}**

Exercise 4: *Determine the mass of the following:*

Mass = Number of Moles x M_r

a) *2 moles of carbon dioxide, CO_2*

Answer
M_r [CO_2] = 44 g mol^{-1}
Mass of 2 moles of carbon dioxide = number of moles x M_r = 2 x 44 = **88 g**

b) *0.01 moles of nitrogen dioxide, NO_2*

Answer
M_r [NO_2] = 48 g mol^{-1}
Mass of 0.01 moles of nitrogen dioxide = number of moles x M_r = 0.01 x 46 = **0.46 g**

c) *1 x 10^{-5} moles of benzene, C_6H_6*

Answer
M_r [C_6H_6 = 78 g mol^{-1}
Mass of 1 x 10^{-5} moles of benzene = number of moles x M_r = 1 x 10^{-5} x 78 = **7.8 x 10^{-4} g**

d) *2.03 x 10^{-3} moles of uranium dioxide, UO_2*

Answer
M_r [UO_2] = 270 g mol^{-1}
Mass of 2.03 x 10^{-3} moles of uranium dioxide = number of moles x M_r = 2.03 x 10^{-3} x 270 = **0.55 g**

e) *1.12 moles of sulphuric acid, H_2SO_4*

Answer
M_r [H_2SO_4] = 98 g mol^{-1}
Mass of 1.12 moles of sulfuric acid = number of moles x M_r = 1.12 x 98 = **109.76 g**

f) *3 x 10^{-4} moles of calcium carbonate, $CaCO_3$*

Answer
M_r [$CaCO_3$] = 100 g mol^{-1}
Mass of 3 x 10^{-4} moles of calcium carbonate= number of moles x M_r = 3 x 10^{-4} x 100 = **0.03 g**

g) *1.2 moles of ethane, C_2H_4*

Answer
M_r [C_2H_4] = 28 g mol^{-1}
Mass of 1.2 moles of ethane = number of moles x M_r = 1.2 x 28 = **33.6 g**

h) *0.5 moles ethanoic acid, CH_3COOH*

Answer
M_r [CH_3COOH] = 60 g mol^{-1}
Mass of 0.5 moles ethanoic acid = number of moles x M_r =0.5 x 60 = **30 g**

i) *1.25 x 10^{-3} moles sodium hydroxide, NaOH*

Answer
M_r [NaOH] = 40 g mol^{-1}
Mass of 1.25 x 10^{-3} moles of sodium hydroxide = number of moles x M_r = 1.25 x 10^{-3} x 40 = **0.05 g**

j) *0.025 moles potassium dichromate, $K_2Cr_2O_7$*

Answer
M_r [$K_2Cr_2O_7$] = 294 g mol^{-1}
Mass of 0.025 moles of potassium dichromate = number of moles x M_r = 0.025 x 294 = **7.35 g**