

Usual Atomic Charges of Main Group Elements

+1 +2

+3 +4 +5 +6 +7

-5 -4 -3 -2 -1

1	1																	2	1					
	H																	He						
	1A (1)	2A (2)	used most commonly at present in the United States.										3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)						
2	3	4																	5	6	7	8	9	10
	Li	Be																	B	C	N	O	F	Ne
3	11	12	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	13	14	15	16	17	18						
	Na	Mg	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr						
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36						
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr						
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54						
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe						
6	55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86						
	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn						
7	87	88	89	104	105	106	107	108	109	110	111	112												
	Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds														

Examples

SO₃ sulfur trioxide
 CO₂ carbon dioxide
 Al₂O₃ aluminum trioxide
 IF₇ iodine heptafluoride

60	61	62	63	64	65	66	67	68	69	70	71
Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
92	93	94	95	96	97	98	99	100	101	102	103
U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Periods are horizontal rows

Groups are vertical columns of elements. Some groups have common names: Group 1A = alkali metals, Group 2A = alkaline earth metals.

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Chemical Equations

A chemical equation—just like a mathematical equation—is a way to express, in symbolic form, the reactions occurring in a chemical system.

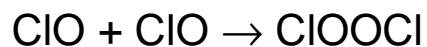
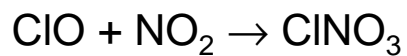
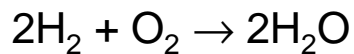
- Balancing chemical equations
- Reaction stoichiometry
- Reagents limiting the extent of reaction
- Acid-base reactions
- Oxidation states of reactants and products



Types of Chemical Reactions

- Combination Reactions:

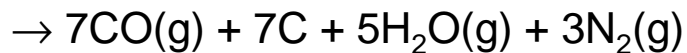
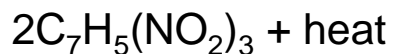
Atoms or molecules combine to form a new molecule



Types of Chemical Reactions

- Decomposition Reactions:

A molecule breaks apart to form different molecules or atoms

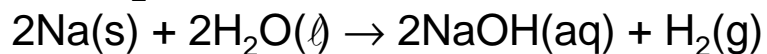
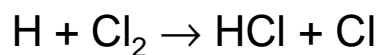




Types of Chemical Reactions

- Displacement Reactions:

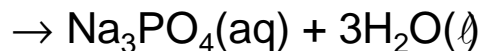
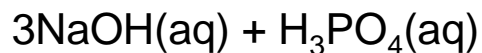
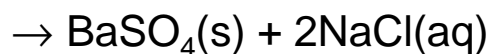
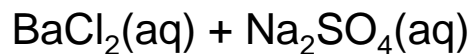
An atom or molecule displaces an atom or molecule in the reaction partner



Types of Chemical Reactions

- Exchange Reactions:

The components of two compounds are exchanged





Balancing Chemical Equations

- Remember *Conservation of Mass* rule—matter is neither created nor destroyed in a chemical reaction.
- A **balanced** chemical equation must have the same number of each type of atom on the reactant side as on the product side.



Balancing Chemical Equations

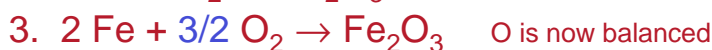
- Process for balancing chemical equations:
 1. Determine correct chemical formulas of all reactants and products
 2. Start with “heavier” atoms—balance number of these on reactant and product sides of equation
 3. If elements appear in equation as either reactants or products, balance these last
 4. Electrical charge must be balanced



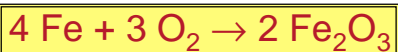
Balanced Chemical Equations

Examples

Write a balanced chemical equation for the reaction of Fe(III) with oxygen to form iron oxide



coefficients must usually be integer numbers—multiply everything by 2 to remove 3/2 denominator:



Balanced Chemical Equations

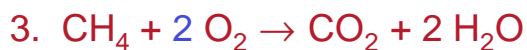
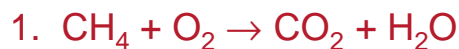
Examples

Write a balanced chemical equation for the combustion of methane—combustion is reaction with oxygen producing a flame. Complete combustion produces only CO_2 and H_2O .

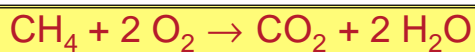


Balanced Chemical Equations

Examples



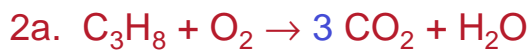
O is now balanced



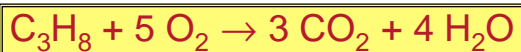
Balanced Chemical Equations

Examples

Combustion of propane, C_3H_8



4. No charges to balance

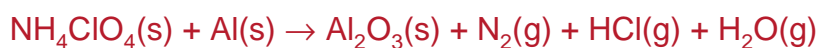




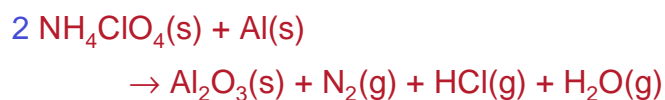
Balanced Chemical Equations

Examples

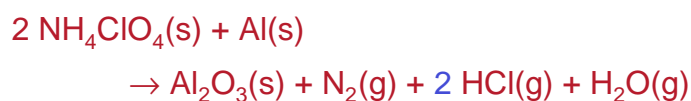
Reaction of ammonium perchlorate with aluminum



2a. Balance N:



2b. Balance Cl:

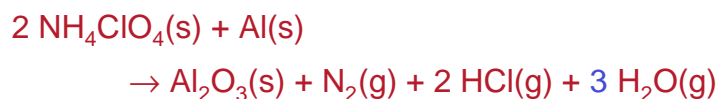


Balanced Chemical Equations

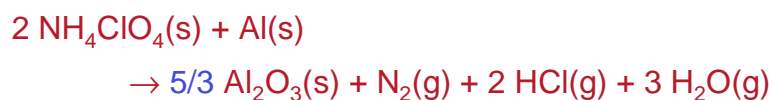
Examples

Reaction of ammonium perchlorate with aluminum (con't.)

2c. Balance H:



2d. Balance O:



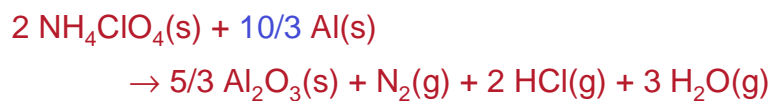


Balanced Chemical Equations

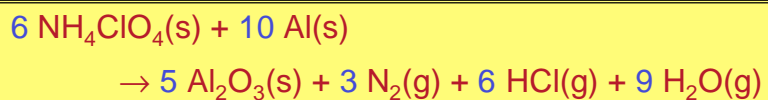
Examples

Reaction of ammonium perchlorate with aluminum (con't.)

3a. Balance Al:

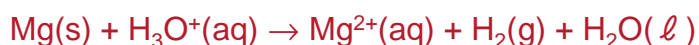


3b. Remove fractional coefficients (multiply by 3):

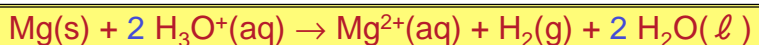


Balanced Chemical Equations

Examples



1. As written, the only element out of balance is the hydrogen—balance H first:



2. Check charge balance:

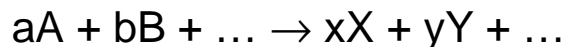
left-hand side has total charge of +2 (2 * 1+ charge on hydronium ion)

Right-hand side has total charge of +2 (2+ charge on Mg ion)



Stoichiometry of Chemical Reactions

For the generic chemical reaction



A, B, X, and Y represent the atoms or molecules reacting and forming, and the coefficients a , b , x , and y represent the **stoichiometric coefficients**—they tell how many moles of one substance reacts with another substance to form some number of moles of the products.



Stoichiometry

It is important to remember that the stoichiometric coefficients represent *numbers of moles*, not masses of reactants and products



Stoichiometry

How much carbon dioxide is produced by burning one gallon of gasoline?

- Gasoline is composed of many hydrocarbons, but let's assume they are all iso-octane (C_8H_{18})
- Isooctane has a density of 0.6980 g mL^{-1}
- $1 \text{ gal} = 3.785 \text{ L} = 3785 \text{ mL}$



Stoichiometry

- Mass of isooctane
 $(0.6980 \text{ g mL}^{-1})(3785 \text{ mL}) = 2642 \text{ g } C_8H_{18}$
- Molar mass:
 $8(12.011 \text{ g mol}^{-1}) + 18(1.0079 \text{ g mol}^{-1})$
 $= 114.230 \text{ g mol}^{-1}$
- Moles C_8H_{18} :
 $(2642 \text{ g}) / (114.230 \text{ g mol}^{-1}) = 23.13 \text{ mol } C_8H_{18}$



Stoichiometry

- Balanced chemical equation:



- Determine moles of CO_2 produced:

$$(23.13 \text{ mol } \cancel{\text{C}_8\text{H}_{18}}) \frac{(16 \text{ mol } \text{CO}_2)}{(2 \text{ mol } \cancel{\text{C}_8\text{H}_{18}})} = 185.0 \text{ mol } \text{CO}_2$$



Stoichiometry

- Determine mass of CO_2 :

$$\begin{aligned} &(185.0 \text{ mol } \text{CO}_2) (44.009 \text{ g mol}^{-1}) \\ &= 8142 \text{ g } \text{CO}_2 = 8.142 \text{ kg } \text{CO}_2 \text{ per gallon} \\ &\text{of gasoline consumed} \end{aligned}$$

- How much CO_2 is emitted by CA every year?

Californians consume $\sim 1.4 \times 10^{10}$ gallons of gasoline each year.

$$\begin{aligned} &(1.4 \times 10^{10} \text{ gal}) (8.142 \text{ kg } \text{CO}_2 \text{ gal}^{-1}) \\ &= 1.1 \times 10^{11} \text{ kg } \text{CO}_2 \end{aligned}$$



Stoichiometry

- The following general expression applies to stoichiometry problems:

$$\text{Moles B} = \frac{(\text{Coefficient B})}{(\text{Coefficient A})} (\text{Moles A})$$

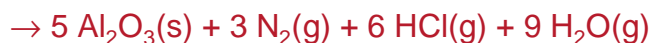


Limiting Reagents

- Suppose the amount of one the reactant in a chemical reaction is insufficient to allow the reaction to proceed to completion. That reactant is called the *limiting reagent*. The limiting reagent limits how much product can formed in a reaction.



Limiting Reagents



- If we begin with 1.00 kg ammonium perchlorate and 0.100 kg aluminum, how many moles of gaseous product will be produced?

1. Which reactant will be consumed first?

$$(1000 \text{ g NH}_4\text{ClO}_4) / (117.488 \text{ g mol}^{-1}) = 8.51 \text{ mol NH}_4\text{ClO}_4$$

$$(100 \text{ g Al}) / (26.982 \text{ g mol}^{-1}) = 3.71 \text{ mol Al}$$



Limiting Reagents

- 1a. How much Al required for NH_4ClO_4 to react completely?

$$\begin{array}{l} (8.51 \text{ mol} \\ \text{NH}_4\text{ClO}_4) \end{array} \quad \frac{(10 \text{ mol Al})}{(6 \text{ mol NH}_4\text{ClO}_4)} = 14.2 \text{ mol Al}$$

Since we only have 3.71 mol Al, there is insufficient Al for the NH_4ClO_4 to react completely, so Al is the limiting reagent.

2. Determine moles of each gaseous product formed in reaction:



Limiting Reagents

$$(3.71 \text{ mol Al}) \frac{(3 \text{ mol N}_2)}{(10 \text{ mol Al})} = 1.11 \text{ mol N}_2$$

$$(3.71 \text{ mol Al}) \frac{(6 \text{ mol HCl})}{(10 \text{ mol Al})} = 2.23 \text{ mol HCl}$$

$$(3.71 \text{ mol Al}) \frac{(9 \text{ mol H}_2\text{O})}{(10 \text{ mol Al})} = 3.34 \text{ mol H}_2\text{O}$$

Total gas phase product = 6.68 mol



Limiting Reagents

Example

Ammonia reacts with nitric oxide to form nitrogen gas and water:



If 71.4 g NH_3 reacts with 168.6 g NO , how much N_2 and H_2O will be produced?

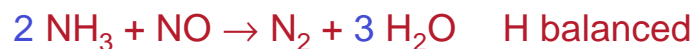
Step 1: Balance the chemical equation



Limiting Reagents

Example (con't.): $\text{NH}_3 + \text{NO} \rightarrow \text{N}_2 + \text{H}_2\text{O}$

Step 1: Balance the chemical equation



remove fractional coefficient



Limiting Reagents

Example (con't.): $\text{NH}_3 + \text{NO} \rightarrow \text{N}_2 + \text{H}_2\text{O}$

Step 2: Determine moles of reactants

$$\frac{71.4 \text{ g NH}_3}{17.031 \text{ g/mol}} = 4.19 \text{ mol NH}_3$$

$$\frac{168.6 \text{ g NO}}{30.006 \text{ g/mol}} = 5.62 \text{ mol NO}$$

Step 3: Determine which is limiting reagent

$$(5.62 \text{ mol NO}) \left(\frac{4 \text{ mol NH}_3}{6 \text{ mol NO}} \right) = 3.75 \text{ mol NH}_3 \quad \text{NO is limiting reagent}$$



Limiting Reagents

Example (con't.): $\text{NH}_3 + \text{NO} \rightarrow \text{N}_2 + \text{H}_2\text{O}$

Step 4: Determine amount of products

$$(5.62 \text{ mol NO}) \frac{(5 \text{ mol N}_2)}{(6 \text{ mol NO})} = 4.68 \text{ mol N}_2$$

$$(4.68 \text{ mol N}_2) (28.014 \text{ g/mol}) = 131 \text{ g N}_2$$

$$(5.62 \text{ mol NO}) \frac{(6 \text{ mol H}_2\text{O})}{(6 \text{ mol NO})} = 5.62 \text{ mol H}_2\text{O}$$

$$(5.62 \text{ mol H}_2\text{O}) (18.0152 \text{ g/mol}) = 101 \text{ g H}_2\text{O}$$



Limiting Reagents

Example

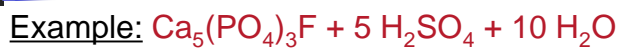


<u>compound</u>	<u>initial mass</u>	<u>initial moles</u>
$\text{Ca}_5(\text{PO}_4)_3\text{F}$	1000. g	1.983 mol
H_2SO_4	200.0 g	2.039 mol
H_2O	100.0 g	5.551 mol

Determine mass of all products formed



Limiting Reagents



Step 1: Determine limiting reagent—examine $\text{Ca}_5(\text{PO}_4)_3\text{F}$

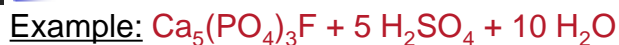
$$(1.983 \text{ mol Ca}_5\text{...}) \frac{(5 \text{ mol H}_2\text{SO}_4)}{(1 \text{ mol Ca}_5\text{...})} = 9.915 \text{ mol H}_2\text{SO}_4 \text{ for complete rxn}$$

$$(1.983 \text{ mol Ca}_5\text{...}) \frac{(10 \text{ mol H}_2\text{O})}{(1 \text{ mol Ca}_5\text{...})} = 19.83 \text{ mol H}_2\text{O for complete rxn}$$

Not enough H_2SO_4 or H_2O to react completely with $\text{Ca}_5(\text{PO}_4)_3\text{F}$
 $\therefore \text{Ca}_5(\text{PO}_4)_3\text{F}$ is not limiting reagent



Limiting Reagents



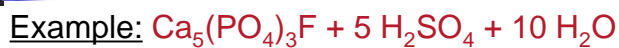
Step 1: Determine limiting reagent—examine H_2SO_4

$$(2.039 \text{ mol H}_2\text{SO}_4) \frac{(10 \text{ mol H}_2\text{O})}{(5 \text{ mol H}_2\text{SO}_4)} = 4.078 \text{ mol H}_2\text{O for complete rxn}$$

H_2O is in excess relative to the amount needed to react completely with H_2SO_4
 $\therefore \text{H}_2\text{SO}_4$ is limiting reagent



Limiting Reagents



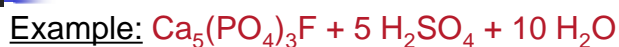
Step 2: Determine amount of product formed

$$(2.039 \text{ mol H}_2\text{SO}_4) \frac{(3 \text{ mol H}_3\text{PO}_4)}{(5 \text{ mol H}_2\text{SO}_4)} = 1.223 \text{ mol H}_3\text{PO}_4 \text{ w}$$

$$(1.223 \text{ mol H}_3\text{PO}_4) (97.995 \text{ g/mol}) = 119.8 \text{ g H}_3\text{PO}_4$$



Limiting Reagents



Step 2: Determine amount of product formed

$$(2.039 \text{ mol H}_2\text{SO}_4) \frac{(5 \text{ mol CaSO}_4 \cdot 2\text{H}_2\text{O})}{(5 \text{ mol H}_2\text{SO}_4)} = 2.039 \text{ mol CaSO}_4$$

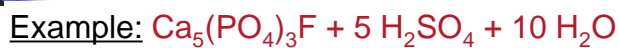
$$(2.039 \text{ mol CaSO}_4 \cdot 2\text{H}_2\text{O}) (172.17 \text{ g/mol}) = 351.1 \text{ g CaSO}_4 \cdot 2\text{H}_2\text{O}$$

$$(2.039 \text{ mol H}_2\text{SO}_4) \frac{(1 \text{ mol HF})}{(5 \text{ mol H}_2\text{SO}_4)} = 0.4078 \text{ mol HF}$$

$$(0.4078 \text{ mol HF}) (20.006 \text{ g/mol}) = 8.158 \text{ g HF}$$



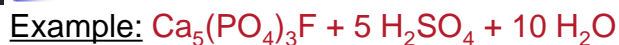
Product Yields



For each kg of $\text{Ca}_5(\text{PO}_4)_3\text{F}$ that reacts, 400. g of phosphoric acid are formed. What is the percent yield of phosphoric acid?



Product Yields



Step 1: Determine the theoretical yield—amount of product formed if reaction occurred completely

$$(1.983 \text{ mol Ca}_5\text{...}) \frac{(3 \text{ mol H}_3\text{PO}_4)}{(1 \text{ mol Ca}_5\text{...})} = 5.949 \text{ mol H}_3\text{PO}_4 \text{ for complete rxn}$$

$$(5.949 \text{ mol H}_3\text{PO}_4) (97.995 \text{ g/mol}) = 583 \text{ g H}_3\text{PO}_4 \text{ theoretical yield}$$

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{400\text{g}}{583\text{g}} \times 100\% = 68.6\%$$