Chemistry Review for the FE Exam

Chemistry topics included on the FE exam:

- Naming
- Redox
- Periodic Table
- States of matter
- Acids & bases
- Equations & stoichiometry
- Equilibrium
- Metals & nonmetals

Which of these topics do you feel you need to work on most?

Physical states of matter

What are the **three physical states** of matter?

Solids, liquids & gases

How are they affected by changing temperature & pressure?

As temperature increases: solid → liquid → gas

As pressure increases: gas → liquid → solid

How do they **differ** in terms of:

- density (abundance) — Solids > liquids > gases
- energy / movement — Gas > liquid > solids
- shape & compressibility

Only gases can be compressed.

Solids have definite shapes, but liquids & gases conform to containers

Examples of each physical state? Pure substances? Mixtures?

Pure substances: iron is a solid; mercury is a liquid; hydrogen is a gas

Mixtures:

- alloys are solid solutions
- coffee with milk & sugar is a liquid
- air is a gaseous solution

Atoms & elements

What's the difference between an **atom** & an **element**?

Atoms are the smallest indivisible form of matter that retain the physical & chemical properties of that matter.

An element is a type of atom with a defined number of p, n & e-.

What are the three **subatomic particles**? What do you know about each?

Protons = + charge, mass of 1 amu, in the nucleus

Neutron = no charge, mass of 1 amu, in the nucleus

Electrons = - charge, mass of 1/2000 amu, surrounding the nucleus

How are subatomic particles arranged to form an atom? **Structure**?

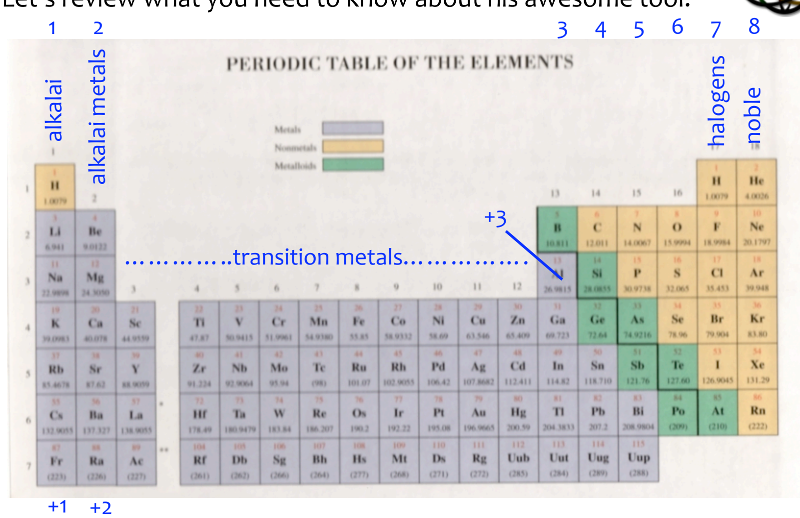
Nucleus = tiny, incredibly dense center of the atom created from all protons and neutrons

Electrons surround the nucleus…. many models for the electrons

- diffuse cloud
- orbiting like planets
- orbitals

The periodic table

Let's review what you need to know about his awesome tool:



- Number subatomics
- Atomic mass
- Column (group)
- Row
- metals
- nonmetals
- mettaloids
- valence electrons
- oxidation numbers

Shells, orbits & orbitals

The **modern atomic** model?

Prior to the modern atomic model (proved by Rutherford in the gold-foil experiment no one knew how subatomic particles were arranged.
Rutherford proved that protons & neutrons form a central nucleus, and that electrons surrounded the nucleus in a diffuse cloud.

The Bohr or **planetary model** of the atom?

Bohr believed that electrons circled the nucleus only at specific, or principle, energy levels.
Like planets orbiting the nucleus, sitting sun-like at the center of the atom.

The **quantum mechanical** model?

The key here is orbitals rather than orbits.

- Electrons still occupy discrete and specific energy levels….
- …but they don't orbit.
- Instead they occupy specific 3D shapes corresponding to those energy levels.
- Orbitals are likely 3D locations of electrons.

Isotopes & ions

What's the difference between an atom and an **isotope**?

Atoms have a defined standard number of neutrons.
Number of neutrons = atomic mass – atomic number
Isotopes have a non-standard number of neutrons (heavy or light)

How do you calculate **average atomic mass**?

Average atomic mass is a weighted average of the masses of all isotopes.

Avg atomic mass = sum of all isotope (frequency)(mass)

What's the difference between an atom and an **ion**?

Atoms are not charged because they have equal numbers of protons & e-.
Ions are atoms that have lost or gained electrons.
Cations = metals that lost e- &are now + charged
Anions = non-metals that gained e- & are now – charged

Why do atoms form ions? What's their motivation? Predicting their **charges**?

Atoms want a full valence shell – an octet for all but H & He
Anions gain to get to 8 ve-
Cations lose to get the the intact valence shell "below" the lost ve-

FE isotopes & ions problems

Which element has the highest ionization energy?

a) Ar ←
b) Cl
c) H
d) Kr ←

FE isotope problems

For a particular isotope, the sum of the atomic number & the atomic mass is 148, and the difference between atomic number & atomic mass is 58. How many protons does this isotope have?

a) 45 — Atomic mass ~2 x protons
b) 58 — Mass – number = neutrons = 58
c) 90 — 148 = (2 x protons) + neutrons
d) 148 — protons = (148 – 58)/2 = 90/2 = 45 = a

Uranium-235 and uranium-238 have the same number of:

a) Neutrons
b) Protons
c) Electrons
d) Protons and electrons ←

Half-life

Radioactive elements degrade over time. The rate at which they are degraded is described by **half-life,** the amount of time it takes for the amount (or concentration) to be reduced by 50%.

$$N = N_o e^{-0.693t/t_{1/2}}$$

What's the half-life of a substance that decays to 25% of its original amount in 6 days?

a) 0.08 d
b) 3 d
c) 8 d
d) 12 d

Solve for t1/2…… $t_{1/2} = \frac{-0.693\,t}{\ln(N/N_o)} = \frac{(-0.693)(6\text{ d})}{\ln(0.25)} = 3\text{ d}$

A given sample of radioactive material has 80% of activity left after 10 years. How much will be left after 90 more years?

a) 0.1%
b) 1.7%
c) 11%
d) 13%

Solve for t1/2…… $t_{1/2} = \frac{-0.693\,t}{\ln(N/N_o)} = \frac{(-0.693)(10\text{ d})}{\ln(0.8)} = 31.06\text{ d}$

$N/N_o = e^{(-0.693)(100\text{ yr})/31.06\text{ yr}} = 0.107$ (11%)

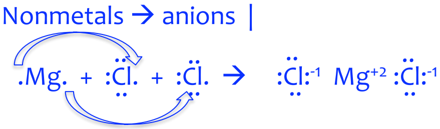
Molecules: ionic & molecular

Why do atoms join to form molecules? What's a **molecule**?

Atoms crave stability and form molecules to get it.
Charged ions "bond" to form uncharged (more stable) compounds.
Non-metal atoms share electrons to form covalent bonds & share into mutual octets.

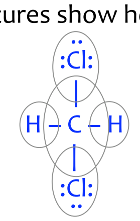
What types of atoms form salts? **Move the electrons** and make it happen?

Metals → cations |__ionic compounds
Nonmetals → anions |



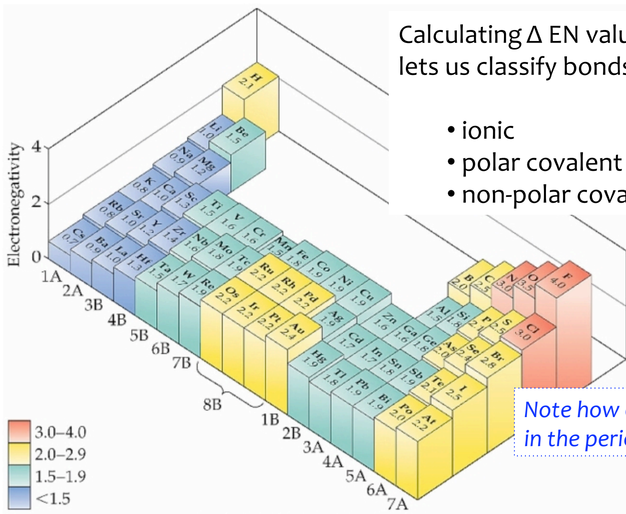
Lewis dot structures show how atoms share electrons in **covalent bonds.**

CH_2Cl_2



Electronegativity & bond polarity

Electronegativity is a measure of an atoms ability to:
1) Hold on to its own electrons
2) Attract electrons away from other atoms



Calculating Δ EN values of 2 bonded atoms lets us classify bonds or molecules as:

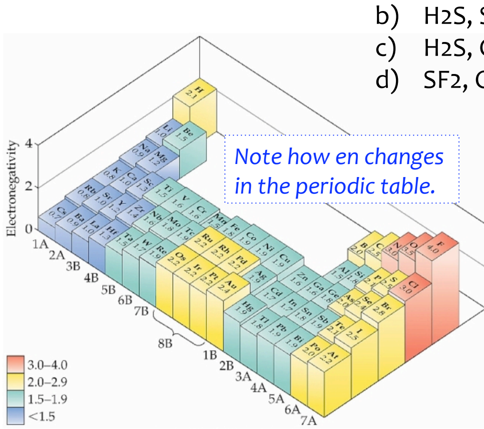
	ΔEN
• ionic	<0.5
• polar covalent	0.5 – 2.0
• non-polar covalent	>2.0

Note how en changes in the periodic table.

FE electronegativity & bond polarity problems

Which element is the most electronegative?
a) Br
b) Cl
c) F ←
d) I

Arrange these in order of increasing polarity of their bonds: SO_2, H_2S, SF_2, OF_2
a) SO_2, H_2S, SF_2, OF_2
b) H_2S, SF_2, SO_2, OF_2
c) H_2S, OF_2, SO_2, SF_2 ←
d) SF_2, OF_2, SO_2, H_2S



Note how en changes in the periodic table.

Naming ionics, moleculars & acids

Ionic formulas must be balanced for a **net charge of zero**.

- mono- vs. polyatomic ions
- transition metals?

Na_2S	sodium sulfide
$Fe(SO_3)$	iron (II) sulfite
$Mn(SO_4)$	manganese (II) sulfate

Acids also need to balance to a net charge of zero.

- mono is hydro_______ acid
- poly _____ite becomes ______ous acid, but ______ate to_______ic acid

H_2S	hydrosulfuric acid
$H_2(SO_3)$	sulfurous acid
$H_2(SO_4)$	sulfuric acid

Molecular compounds don't have to be net zero, but turn #s into pre-fixes.

P_4S_7	tetraphosphorous heptasulfide
NO	~~mono~~nitrogen monoxide
SF_9	sulfur nonasulfide

FE formula & naming questions

Which of these compounds is ionic?

a) CO
b) NO
c) I_2
d) KCl ← metal + non-metal

Which formula is incorrect?

a) $Ca(OH)_2$
b) $Na_2(CO_3)$
c) CaCl ← Should be $CaCl_2$
d) K(OH)

What are the formulas of: aluminum nitrate, magnesium hydroxide, calcium oxide, copper (II) carbonate *[cupric carbonate]*?

a) $Al(NO_3)_3$, $Mg(OH)_2$, CaO, $Cu(CO_3)$ ←
b) $Al_2(NO_3)$, $Mg(OH)$, CaO_2, $Cu(CO_3)$
c) $Al(NO_3)$, $Mg(OH)_2$, CaO, $Cu(CO_3)_2$
d) $Al(NO_3)$, $Mg(OH)$, Ca_2O_3, $Cu(CO_3)$

Moles

Unit of "**amount**" for atoms, isotopes, ions or molecules.

1 mole = number of atoms in 12 g of ^{12}C = 6.02×10^{23} atoms/molecules

1 mole of gas occupies 22.4 L at STP (25°C, 1 atm)

Mole fraction of x = mole of x / total moles

A gas mixture is made by combining 2 kg of O2, 5 kg of N2 & 3 kg of Xe.
What's the mole fraction of O2 gas?

$O_2 = \frac{2000\ g \quad 1\ mol}{32\ g} = 0.0625\ mol\ O_2$

$N_2 = \frac{5000\ g \quad 1\ mol}{28\ g} = 0.1786\ mol\ N_2$

$Xe = \frac{3000\ g \quad 1\ mol}{131.3\ g} = 0.0228\ mol\ Xe$

0.0625 O2/ 0.2639 mol total
= 0.2368 mole fraction

Molar mass (aka molecular weight) = the mass of one mole (g/mol)

Calculate the MW of $H_2(SO_4)$.

MW = (2x1.01) + (32.02) + (4x15.99) = ~98 g/mol

FE mole questions

How many electrons are in 0.01 g of gold?

The atomic mass of gold is 196.97 g/mole, atomic number 79

$\frac{0.01\ g}{} \quad \frac{1\ mole}{196.97\ g} \quad \frac{6.02 \times 10^{23}\ atoms}{1\ mole} \quad \frac{79\ e^-}{1\ atom} = 2.42 \times 10^{21}\ e^-$

Which is not about a mole?

a) 22.4 L N2 at STP
b) 6.02×10^{23} O2 molecules
c) 16 g O2 ← 1 mol ~ 32 g O2
d) 2 g of H2

Percent composition

Percent composition tells us how much of a molecule's mass is made up of each of the molecule's elements.

Think of the part vs. the whole.

An unknown compound is 49.3% C, 9.6% H 21.9% O and 19.2% N. Molecular formula?

a) C_4H_8NO
b) C_4H_6NO
c) $C_3H_6N_2O$
d) C_3H_7NO

Convert percentage to grams to moles, ratios:

49.3 g 1 mol = 4.11 mol C/1.37 = 3
12.01 g

9.6 g 1 mol = 9.50 mol H/1.37 = 6.9 C_3H_7ON
1.01 g

21.9 g 1 mol = 1.37 mol O/1.37 = 1
15.99 g

19.2 g 1 mol = 1.37 mol N/1.37 = 1
14.01 g

FE percent composition problems

What is the % composition (gravimetric percentage) of oxygen in K_2CrO_4?

a) 33%
b) 42%
c) C57%
d) 66%

Calculate MW, and then look at total O mass as % of that whole:

MW = 194.18

Ox4 = (15.99)(4) ~ 64

64/194.18 = 32.9%

Empirical formulas

Empirical formulas are simplified versions of molecular formulas that tell us the lowest possible ratio of atoms in the molecule.
EF doesn't give us enough information to "build" the molecule.

A student finds that a compound contains 2.7626 g of lead, 0.00672 g of H, and 0.8534 g of oxygen. What's its empirical formula?

a) Pb_2O_4H
b) Pb_4O_2H
c) Pb_4OH_2
d) Pb_2O_8H ←

First express each element as a % of total mass, 3.6227 g:
Pb = 76.2%, O = 23.6%, H = 0.185%

Then… make % into grams & go to moles

$\frac{76.2\ g \quad 1\ mol}{207.19\ g} = 0.367\ mol/0.183 = 2$

$\frac{23.6\ g \quad 1\ mol}{15.99\ g} = 1.47\ mol/0.183 = 8$

$\frac{0.185\ g \quad 1\ mol}{1.01\ g} = 0.183\ mol/0.183 = 1$

So, Pb_2O_8H

Chemical equations

Chemical equations show **change of molecular identity**.

The atoms don't change, but they are taken apart & rearranged.

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

reactants → (change) → products

The carbon loses its hydrogen & hooks up with oxygen, creating CO_2.
Some of the oxygen combines with hydrogen to make water.

Equations must be **balanced**.

Same number & type of atoms on either side of the arrow.
Good idea to save O & H for last.

Stoichiometry uses the coefficients of balanced equations to predict yields.

1 mole of propane + 5 moles of oxygen -- react to form →
3 moles of carbon dioxide + 4 moles of water

Typical chemical reactions

- Combination $A + B \rightarrow AB$
- Decomposition $AB \rightarrow A + B$
- Combustion $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  Fuel + oxygen carbon dioxide + water
- Exchange $2Na_3N + 3CaCl_2 \rightarrow 6NaCl + Ca_3N_2$
  - Precipitation 2Ag~~(NO3)~~ + ~~Ca~~Br2 → 2AgBr + ~~Ca(NO3)~~2 ($2Ag(NO_3) + CaBr_2 \rightarrow 2AgBr + Ca(NO_3)_2$)
  - Neutralization $2H_3(PO_4) + 3Ca(OH)_2 \rightarrow 6H(OH) + Ca_3(PO_4)_2$
- Redox displacement $Mg + 2HCl \rightarrow H_2 + MgCl_2$
  0 +1/-1 0 +2/-1
  ox red

FE balancing questions

Balance this equation:

$Al + H_2(SO_4) \rightarrow Al_2(SO_4)_3 + H_2$

$2Al + 3H_2(SO_4) \rightarrow Al_2(SO_4)_3 + 3H_2$

What is the smallest possible coefficient of $Na_2(CO_3)$ when this reaction is balanced: $Na_2(CO_3) + HCl \rightarrow NaCl + H_2O + CO_2$

$Na_2(CO_3) + 2HCl \rightarrow 2NaCl + H_2O + CO_2$

one

Balance this equation: $FeS_2 + O_2 \rightarrow Fe_2O_3 + SO_2$

$2(2FeS_2 + 11/2O_2 \rightarrow Fe_2O_3 + 4SO_2)$

$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$

Precipitation reactions

TABLE 4.1 Solubility Guidelines for Common Ionic Compounds in Water

Soluble Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	$C_2H_3O_2^-$	None
	Cl^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	Br^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	I^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}
Insoluble Compounds		**Important Exceptions**
Compounds containing	S^{2-}	Compounds of NH_4^+, the alkali metal cations, and Ca^{2+}, Sr^{2+}, and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
	PO_4^{3-}	Compounds of NH_4^+ and the alkali metal cations
	OH^-	Compounds of the alkali metal cations, and Ca^{2+}, Sr^{2+}, and Ba^{2+}

Acids, bases & neutralization reactions

Acids can donate H ions (begin with H)
Bases can accept H ions (typically OH- or NH3)

pH is a logarithmic scale of acidity = -log $[H^{+1}]$ so this scale is inverse

Calculate the pH values of 0.1 M and 0.01 M HCl solutions.
pH = - log 0.1 M = 1
pH = - log 0.01 M = 2

To go the other way? Calculate the H ion concentration of solutions whose pH values are 6.0 and 7.0.
$[H^{+1}] = 10^{-6}$ and 10^{-7}

Acids & bases react via exchange to produce salt & water:
3H2(SO4) + 2Al(OH)3 → Al2(SO4)3 + 6H(OH)
low pH high pH no pH neutral pH 7

FE acid & base problems

A 1.0 M solution of HCl has a pH of 1.1. What is the percent of the acid that is ionized?

$pH = 1.1 = -\log[H^{+1}]$ -> $\log[H^{+1}] = -1.1$ -> $[H^{+1}] = 10^{-1.1} = 0.079$ M

So, 79% (?) is ionized.

If you need to neutralize 4 g of Na(OH) dissolved in 1 L of water, you will need 1 L of:

a) 0.001 M HCl
b) 0.01 M HCl
c) 0.1 M HCl
d) 1.0 M HCl

MW of Na(OH) = 40 g/mol

$\frac{4\ g}{} \frac{1\ mole}{40\ g} \frac{}{1\ L} = 0.1$ M

Since the acid and base react with a 1:1 stoichiometry, the answer is c.

$Na(OH) + HCl \rightarrow NaCl + H_2O$

Solution stoichiometry

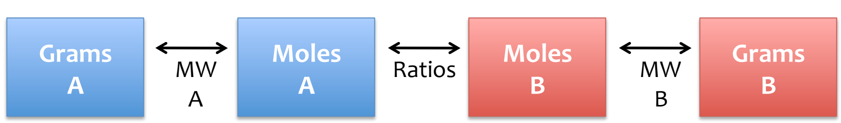
Limiting reactants – the reactant that is completely consumed in a chemical reaction; rxn yield is dependent on the limiting reactant.

$3H_2(SO_4)$ +	$2Al(OH)_3$ →	$Al_2(SO_4)_3$ +	$6H(OH)$
3 moles	1 mole	? moles	? moles
			0.5 3
100 g	100 g	? g	? g

$\frac{100\ g}{} \frac{1\ mol}{98\ g} \frac{1\ Al_2(SO_4)_3}{3\ H_2(SO_4)} \frac{340\ g}{1\ mol} = 115.6$ g $Al_2(SO_4)_3$ *** limiting/theor yield

$\frac{100\ g}{} \frac{1\ mol}{77\ g} \frac{1\ Al_2(SO_4)_3}{2\ Al(OH)} \frac{340\ g}{1\ mol} = 220.8$ g $Al_2(SO_4)_3$

Percent yield =



FE stoichiometry problem

How many kg of NaOH are made from 2000 kg of Na2(CO3) by the following reaction. Assume there is excess Ca(OH)2.

$$Na_2(CO_3) + Ca(OH)_2 \rightarrow 2Na(OH) + Ca(CO_3)$$

MW of NaOH = 40 g/mole
MW of Na2(CO3) = 106 g/mole

$$\frac{2000\ kg}{} \cdot \frac{1000\ g}{1\ kg} \cdot \frac{1\ mol}{106\ g} \cdot \frac{2\ mol\ Na(OH)}{1\ mol\ Na_2(CO_3)} \cdot \frac{40\ g}{1\ mol} \cdot \frac{1\ kg}{1000\ g} = 1509$$

Redox reactions

What are oxidation & reduction? **Oxidation numbers**?

- Metals usually take their charge
- H = +1/1
- O = -2
- F = -1
- C, N, S, others vary

Molecule's ox # sum to zero
Ion ox # sum to ionic charge

What are **reducing and oxiding agents?**

The element that is oxidized is the reducing agent.
The element that is reduced is the oxidizing agent.

Sacrificial anodes, cathodic protection & galvanization

FE redox problems

In the following rxn, which elements are reducing & oxidizing agents: $2Mg + O_2 \rightarrow 2MgO$

0 0 +2/-2 Mg is oxidized = reducing agent

O is reduced = oxidizing agent

Break this reaction into half-equations and balance for electrons:

$2Na + Cl_2 \rightarrow 2NaCl$

$2Na \rightarrow 2Na^{+1} + 2e^-$ oxidation (e- with products)

$Cl_2 + 2e^- \rightarrow 2Cl^{-1}$ reduction (e- with reactants)

Redox FE questions

What are the oxidation numbers of atoms in ClO_3^{-1} & MnO_4^{-1} ions?

$ClO_3^{-1} \rightarrow$ Cl? +5 So calculate the ox # of Cl so sums to -1

-2 x 3 = <u>-6</u>

-1

$MnO_4^{-1} \rightarrow$ Mn? +7 So calculate the ox # of Mn so sums to -1

-2 x 4 = <u>-8</u>

-1

Look at this equation: $2H(NO_3) + 3H_2S \rightarrow 2NO + 4H_2O + 3S$

+1/+5/-2 +1/-2 +2/-2 +1/-2 0

a) What's oxidized? S goes from -2 to zero
b) What's reduced? N goes from +5 to +2
c) What's the oxidizing agent? N
d) What's the reducing agent? S

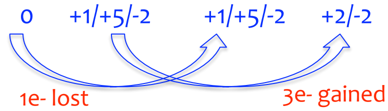
Redox FE questions

Given this unbalanced equation, how many moles of Ag(NO3) are formed for each molecule of NO produced?

Ag + H(NO3) → Ag(NO3) + NO + H2O

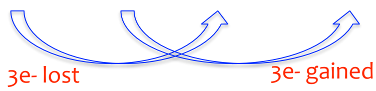
Ag + H(NO3) → Ag(NO3) + NO + H(OH)

0 +1/+5/-2 +1/+5/-2 +2/-2 +1/-2



3Ag + H(NO3) → 3Ag(NO3) + NO + H(OH)

0 +1/+5/-2 +1/+5/-2 +2/-2 +1/-2



Chemical equilibrium

What is **equilibrium**? What factors affect equilibrium?

Equilibrium occurs when two opposite chemical reactions are happening simultaneously:

reactants ⇄ ***products***

Many chemical reactions are equilibrium reactions

Equilibrium constants, **Keq** and direction of reaction.

A + B → C + D

$$Keq = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

Keq = 1, neither favored

Keq > 1, products are favored

Keq < 1, reactants are favored

Le Châtelier's Principle predicts the direction in shift of an equilibrium reaction when the reaction is stressed or when conditions change.

FE equilibrium problems

Here's a reversible chemical reaction in which all reactants & products are gases.

$$N_2 + 3H_2 \rightleftarrows 2NH_3 + \text{heat}$$

What happens if the pressure in the reaction container is doubled?

a) Amount of NH3 doubles
b) No change in amount of NH3
c) More NH3 is made ←
d) Amount of NH3 falls by half

FE equilibrium problems

A liter of solution contains 52.7 g of H2(SO4), 240.8 g of KMnO4, 11.3 g of K2(SO4), 5.5 g of Mn2O7. This reaction happens

$$H_2(SO_4) + 2KMnO_4 \rightleftarrows K_2(SO_4) + Mn_2O_7 + H_2O$$

MW are shown here:

H2(SO4)	98 g/mol
KMnO4	158 g/mol
K2(SO4)	174 g/mol
Mn2O7	222 g/mol
H2O	18 g/mol

What's the Keq?

a) 0.0013 ←
b) 0.0026
c) 0.0052
d) 0.0069

$$H_2(SO_4) = \frac{52.7\ g/L}{98\ g/mol} = 0.538\ M$$

$$KMnO_4 = \frac{240.9\ g/L}{158\ g/mol} = 1.524\ M$$

$$K_2(SO_4) = \frac{11.3\ g/L}{174\ g/mol} = 0.065\ M$$

Keq = 1, neither favored
Keq > 1, products are favored
Keq < 1, reactants are favored

$$Mn_2O_7 = \frac{5.5\ g/L}{222\ g/mol} = 0.025\ M$$

$$K_{eq} = \frac{(0.065)(0.025)}{(0.538)(1.524)^2} = 0.0013$$