Fundamentals of Engineering Exam - General Chemistry Review

General Concepts:

1 mole = "1 gram-mole" = 6.022×10^{23} units = Avogadro's number

atom = smallest part of matter that retains the properties of an element
= composed of protons (positively charged) and neutrons (uncharged) in the nucleus, and electrons (negatively charged) in orbitals around the nucleus.

element = a form of pure matter that contains atoms with the same atomic number (i.e. number of protons in the nucleus).

isotope = an atom of a particular element that has a set number of protons but a varying number of neutrons and mass.

mass number = the number of protons and neutrons in a nucleus.

atomic mass unit (a.m.u.) = the unit of mass that is used to describe the masses of atoms.
= equivalent to $1/(6.022 \times 10^{23})$ of a gram.

Nomenclature and Common Polyatomic Ions:

Formula	Name
H_3O^+	Hydronium ion
NH_4^+	Ammonium ion
CH_3COO^-	Acetate ion
CO_3^{2-}	Carbonate ion
HCO_3^-	Bicarbonate ion
ClO^-	Hypochlorite ion
ClO_2^-	Chlorite ion
ClO_3^-	Chlorate ion
ClO_4^-	Perchlorate ion
OCN^-	Cyanate ion
SCN^-	Thiocyanate ion

Formula	Name
CN^-	Cyanide ion
OH^-	Hydroxide ion
NO_2^-	Nitrite ion
NO_3^-	Nitrate ion
MnO_4^-	Permanganate ion
PO_4^{3-}	Phosphate ion
SO_3^{2-}	Sulfite ion
SO_4^{2-}	Sulfate ion
$S_2O_3^{2-}$	Thiosulfate ion
CrO_4^{2-}	Chromate ion
$Cr_2O_7^{2-}$	Dichromate ion

number of atoms	prefix	number of atoms	prefix
1	mono*	6	hexa
2	di	7	hepta
3	tri	8	octa
4	tetra	9	nona
5	penta	10	deca

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Periodic Trends and the Periodic Table:

states of matter = solids (s) liquids (l) and gases (g)

metals, non-metals, and semi-metals

periodic table = arranged in rows of increasing atomic number and columns of increasing valence shells

periodicity (or "periodic trend") = similarities across rows and down columns of the periodic table

ionization (potential) energy = energy required for the process: $X \rightarrow X^+ + e^-$, in the gas phase
= the periodic trend is that IE increases "left to right" and "bottom to top"

electron affinity = energy associated with the process: $X + e^- \rightarrow X^-$, also in the gas phase
= trend is that EA becomes more favorable "left to right" and "bottom to top"

atomic radius trend = decreases "left to right" and "bottom to top"

effective nuclear charge (Z_{eff}) trend = increases "left to right" and "bottom to top"

ionic radius = cations (+) are smaller than corresponding atom; anions (−) are larger than corresponding atom

octet = the situation corresponding to an atom having 8 valence electrons
= very stable "noble gas configuration"

Stoichiometry:

balanced chemical equation = the relationship between the reactants and products of a reaction that gives the molar ratios of each
= all of the atoms of each element appear to the same extent on each side of the reaction
= needed to determine:
theoretical and percent yields
limiting reagents
empirical formulae

stoichiometry = any calculations based on the balanced equation

stoichiometric coefficient = the molar relationship between the chemical species in the balanced equation

molar mass = mass (in grams) of 1 mole of a substance based on its molecular
formula

Solution Stoichiometry:

solution = a homogeneous mixture of substances where one of the species
(the "solvent") is present to a greater extent than the other(s) (the
"solute(s)")

aqueous solution (or "aqueous phase") = a solution where water is the solvent
= solutes in aqueous solutions are labeled (aq)

concentration units = the convenient way of describing the relative amounts of the
solutes in a solution:

$$\text{molarity} = M = \frac{moles\ solute}{liter\ solution} \quad \text{(molar)}$$

$$\text{molality} = m = \frac{moles\ solute}{kg\ solvent} \quad \text{(molal)}$$

$$\text{normality} = N = \frac{mole\ equivalents}{L\ solution} \quad \text{(normal)}$$

where an "equivalent" is the number of charges transferred as either
e^- (electrons, in redox reactions) or as H^+ ions (protons, in acid-base
reactions)

$$\text{mole fraction} = X_a = \frac{moles\ a}{total\ moles}$$

Ideal Gas Law:

ideal gas = a simplified model gas where the particles do not interact

Boyle's law = relationship between pressure and volume of a gas (P α 1/V)

Charles' law (and Gay-Lussac's law) = relationship between volume and absolute
temperature of a gas (V α T)

Avogadro's law = relationship between volume and moles of a gas (V α n)

ideal gas law = the "equation of state" for an ideal gas, which combines all of the

empirical gas laws above
= relates the thermodynamic properties of an ideal gas to each other
= "P V = n R T", where P is pressure, V is volume, n is moles, and T is absolute temperature

gas law constant (R) = proportionality constant for the ideal gas law
= 0.082 L-atm/mol•K = 8.314 J/mol•K

Dalton' law (of partial pressures) = each gas in a mixture exerts a "partial pressure" which adds to the others to give the total pressure
= "$P_{total} = \sum P_i$" where $P_i = X_i P_{total}$ is the partial pressure of gas "i"

gas-phase stoichiometry = one of the reactants and/or products is a gas
= use partial pressures instead of usual mass or mole units to describe the amount of gaseous species

Properties of Solutions:

colligative properties = the physical characteristics of a solution that depend on the amount of solute (i.e. concentration)

van't Hoff factor (i) = the multiplicative factor that describes the extent of dissociation of a solute in a solution

vapor pressure lowering (Raoult's law) = the amount of vapor produced by the solvent is reduced in the presence of the solute ($P = X P°$)

boiling point elevation = the temperature required to boil as solution is higher than that of the pure solvent ($\Delta T_b = i \, m \, K_b$)

freezing point depression = the temperature required to freeze a solution is lower than that of the pure solvent ($\Delta T_f = -i \, m \, K_f$)

Chemical Equilibrium:

mass action expression = reaction quotient, Q
= a comparison between the relative amounts of products to reactants
= $Q = \dfrac{\left[prod\right]^{v_p}}{\left[react\right]^{v_r}}$, where the brackets mean molar concentrations and v are the stoichiometric coefficients

Note: the amounts of pure liquids and solids are omitted from the mass action expression, and gaseous species are usually included in terms of their partial pressures

equilibrium constant (K_{eq}) = the value that Q takes when equilibrium has been reached

equilibrium = point when a reaction seems to stop
= point when forward and reverse reactions occur at the same rate

Note: reactions proceed in such a way that Q approaches K:
if Q < K, the forward reaction occurs
if Q > K, the reverse reaction occurs

Le Châtellier's principle = a description of how a system at equilibrium reacts to outside stimuli in order to re-achieve equilibrium:
If more reactant is added, forward reaction occurs
If more product is added, reverse reaction occurs
If product is removed, forward reaction occurs

Acids and Bases:

acid (designated as "HA") = a substance that produces H_3O^+ in water by adding an H^+ to H_2O [$HA + H_2O \leftrightarrows A^- + H_3O^+$]
= also donates an H^+ to a base

base (designated as "B") = a substance that produces OH^- in water by accepting an H^+ from H_2O [$B + H_2O \leftrightarrows BH^+ \; OH^-$]
= also accepts an H^+ from an acid [$B + HA \leftrightarrows BH^+ + A^-$]

conjugate pairs = the B and BH^+ and the HA and A^-

neutralization = when an acid and a base react to produce water

auto-hydrolysis of water = the reaction between two water molecules:
$$2\, H_2O \leftrightarrows H_3O^+ + OH^-$$
= has an equilibrium constant $K_w = [H_3O^+][OH^-] = 10^{-14}$
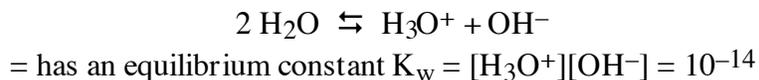
$pH = -\log [H^+] = -\log[H_3O^+] = 14 - \log[OH^-]$

REDOX:

oxidation = the loss of electrons: $X \rightarrow X^{n+} + n\, e^-$

reduction = the gain of electrons: $Y + m\, e^- \rightarrow Y^{m-}$

redox = oxidation and reduction occuring simultaneously

oxidizer = oxidizing agent = a substance that causes oxidation in something else, but is itself reduced

reducer = reducing agent = a substance that causes reduction, but is itself oxidized

oxidation state (or oxidation number) = the relative number of valence electrons in an atom as compared to a single atom of the element
= the same as the charge for monatomic ions

Oxidation Number Rules (in order of <u>precedent</u>):

1) **For atoms in <u>neutral compounds</u>, the total of all oxidation numbers (ox#'s) is zero.**

For polyatomic or isolated <u>ions</u>, the total ox# count = overall charge on the ion
total ox#(Fe^{2+}) = +2,
total ox#(CO_2) = 0
total ox#(CrO_4^{2-}) = –2

2) **All group 1 metals (Li, Na, K, …) have ox# = +1,**
All group 2 metals (Be, Mg, …) have ox# = +2
$CaCl_2$: **2** + [2 * (ox#(Cl)] = 0

3) **fluorines *in compounds* have ox# = –1**
SF_4: ox#(S) + [4 * (**–1**)] = 0

4) **hydrogens *in compounds* have ox# = +1**
(exception: H bound to metal have ox# = –1)
H_3O^+: ox#(O) + [3 * (**+1**)] = +1
AlH_3: ox#(Al) + [3 * (**–1**)] = 0

5) **oxygens *usually* have ox# = –2**
ClO_4^-: ox#(Cl) + [4 * (**–2**)] = –1

6) **In compounds with *metals*, group 7A elements have ox# = –1, group 6A elements have ox# = –2**
and group 5A elements have ox# = –3.
$CrBr_3$: ox#(Cr) + [3 * (**–1**)] = 0

Oxidation numbers of Nonmetals

Maximum ox# = Group Number (old system) {Group Number – 10 (new system)}

Minimum ox# = Group Number - 8 (old system) {Group Number – 18 (new system)}

Thermochemistry and Thermodynamics:

thermochemical data = the amount of heat (energy) transferred to or from a
reaction
= enthalpy change (ΔH) of a reaction

endothermic = ΔH is positive, heat is added to the reaction

exothermic = ΔH is negative, heat is released by the reaction

Hess' law = the statement that the enthalpy changes for reactions are additive:

$$\Delta H_{rxn} = \sum \nu_{prod} \Delta H°_f(prod) - \sum \nu_{react} \Delta H°_f(react)$$

$$\Delta H_{rxn}(gas) = (bonds\ broken) - (bonds\ formed)$$

Gibbs free energy change (ΔG) = a measure of spontaneity for a reaction
= obeys the equation "$\Delta G = \Delta H - T\Delta S$":

ΔG = +; non-spontaneous in forward direction
ΔG = –; spontaneous in forward direction
ΔG = 0; equilibrium (neither forward nor reverse reaction)

thermodynamics of equilibrium = relationship between ΔG and Q and K
= follows "$\Delta G = \Delta G° + RTlnQ$" where "$\Delta G° = -RTlnK$"

Solubility Products:

solubility rules = qualitative description of which ions formed insoluble salts

solubility = the extent to which a salt is able to dissolve in water (given in g/mL)

solubility product = the equilibrium constant for the dissolution process
= given the symbol K_{sp}

common ion effect = the name given to the lowering of the solubility of salts in
the presence of high concentrations of one of the ions in the salt (e.g. AgCl
is less soluble in the presence of Cl^- ions from NaCl)