Self-study Notes on OpenStax AP Chemistry Books and Other Resources

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Todo list

1 Atoms, Molecules, and Ions

1.1 Chemical Formulas

1.2 The Periodic Table

The Periodic Table is like the mathematical axioms of chemistry. Everyone interested in chemistry should know these axioms readily. There are so many ways in which you can look at the Periodic Table! The ultimate resource for the periodic table is https://ptable.com.

Table 1: Element's class legend

Reactive nonmetal
Alkali metal
Alkaline earth metal
Lanthanoids
Actinoids
Transition metals
Post-transition metals
Metalloids
Unknown

Table 2: The Periodic Table of Elements

Z	Symbol	Name	$A_{r,\text{ short}}$
1	H	Hydrogen	1.008
2	He	Helium	4.0026
3	Li	Lithium	6.94
4	Be	Beryllium	9.0122
5	B	Boron	10.81
6	C	Carbon	12.011
7	N	Nitrogen	14.007
8	O	Oxygen	15.999
9	F	Fluorine	18.998
10	Ne	Neon	20.18
11	Na	Sodium (Natrium)	22.99
12	Mg	Magnesium	24.305
13	Al	Aluminum	26.982
14	Si	Silicon	28.085
15	P	Phosphorus	30.974
16	S	Sulfur	32.06
17	Cl	Chlorine	35.45
18	Ar	Argon	39.95
19	K	Potassium (Kalium)	39.098
20	Ca	Calcium	40.078
21	Sc	Scandium	44.956
22	Ti	Titanium	47.867
23	V	Vanadium	50.942
24	Cr	Chromium	51.996
25	Mn	Manganese	54.938
26	Fe	Iron (Ferrum)	55.845
27	Co	Cobalt	58.933
28	Ni	Nickel	58.693
29	Cu	Copper	63.546
30	Zn	Zinc	65.38
31	Ga	Gallium	69.723
32	Ge	Germanium	72.63
33	As	Arsenic	74.922
34	Se	Selenium	78.971
35	Br	Bromine	79.904
36	Kr	Krypton	83.798
37	Rb	Rubidium	85.468
38	Sr	Strontium	87.62
39	Y	Yttrium	88.906
40	Zr	Zirconium	91.224
41	Nb	Niobium	92.906

42	Mo	Molymbdenum	95.95
43	Tc	Technetium	(98)[1]
44	Ru	Ruthenium	101.07
45	Rh	Rhodium	102.91
46	Pd	Palladium	106.42
47	Ag	Argentum (Silver)	107.87
48	Cd	Cadmium	112.41
49	In	Indium	114.82
50	Sn	Stannum (Tin)	118.71
51	Sb	Stibium (Antimony)	121.76
52	Te	Tellurium	127.60
53	I	Iodine	126.90
54	Xe	Xenon	131.29
55	Cs	Caesium	132.91
56	Ba	Barium	137.33
57	La	Lanthanum	138.91
58	Ce	Cerium	140.12
59	Pr	Praseodymium	140.91
60	Nd	Neodymium	144.24
61	Pm	Promethium	(145)
62	Sm	Samarium	150.36
63	Eu	Europium	151.96
64	Gd	Gadolinium	157.25
65	Tb	Terbium	158.93
66	Dy	Dysprosium	162.50
67	Ho	Holmium	164.93
68	Er	Erbium	167.26
69	Tm	Thulium	168.93
70	Yb	Ytterbium	173.05
71	Lu	Lutetium	174.97
72	Hf	Hafnium	178.49
73	Ta	Tantalum	180.95
74	W	Wolfram (Tungsten)	183.84
75	Re	Rhenium	186.21
76	Os	Osmium	190.23
77	Ir	Iridium	192.22
78	Pt	Platinum	195.08
79	Au	Aurum (Gold)	196.97
80	Hg	Hydrargyrum (Mercury)	200.59
81	Tl	Thallium	204.38
82	Pb	Plumbum (Lead)	207.2
83	Bi	Bismuth	208.98

[1] This and other values in a pair of parentheses indicates the absence of a *stable* isotope.

84	Po	Polonium	(209)
85	At	Astatine	(210)
86	Rn	Radon	(222)
87	Fr	Francium	(223)
88	Ra	Radium	(226)
89	Ac	Actinium	(227)
90	Th	Thorium	232.04
91	Pa	Protactinium	231.04
92	U	Uranium	238.03
93	Np	Neptunium	(237)
94	Pu	Plutonium	(244)
95	Am	Americium	(243)
96	Cm	Curium	(247)
97	Bk	Berkelium	(247)
98	Cf	Californium	(251)
99	Es	Einsteinium	(252)
100	Fm	Fermium	(257)
101	Md	Mendelevium	(258)
102	No	Nobelium	(259)
103	Lr	Lawrencium	(266)
104	Rf	Rutherfordium	(267)
105	Db	Dubnium	(268)
106	Sg	Seaborgium	(269)
107	Bh	Bohrium	(270)
108	Hs	Hassium	(277)
109	Mt	Meitnerium	(278)
110	Ds	Damstadtium	(281)
111	Rg	Roentgenium	(282)
112	Cn	Copernicium	(285)
113	Nh	Nihonium	(286)
114	Fl	Flerovium	(289)
115	Mc	Moscovium	(290)
116	Lv	Livermorium	(293)
117	Ts	Tennessine	(294)
118	Og	Oganesson	(294)

Elements are classified as:

- Metals
  - Alkali metals (Li, Na, K, Rb, Cs, Fr)
  - Alkaline earth metals (Be, Mg, Ca, Sr, Ba, Ra)

  - Lanthanoids (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu)
  - Actinoids (Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr)
  - Transition metals (Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn,
    Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd,
    Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg,
    Rf, Db, Sg, Bh, Hs)
  - Post-transition metals (Al, Ga, In, Sn, Tl, Pb, Bi, Po)

- Metalloids (B, Si, Ge, As, Sb, Te, At)

- Nonmetals

  - Reactive nonmetals (H, C, N, O, F, P, S, Cl, Se, Br, I)
  - Noble gases (He, Ne, Ar, Kr, Xe, Rn)

1.3 Molecular and Ionic Compounds

In ordinary chemical reactions, the nucleus of each atom (and thus the identity of the element) remains unchanged. Electrons, however, can be added to atoms, removed from atoms, or shared with other atoms. **The transfer and sharing of electrons govern the chemistry of the elements**.

During the formation of some compounds, atoms gain or lose electrons, and form *electrically charged* particles called *ions*. Main-group (or main-block) elements are the elements in groups 1-2 and 13-18. Many people have argued[2] that group-12 elements: Zn(30), Cd(48), and Hg(80) should also be called the main-group elements. They tend to lose electrons to form cations. The trend is predictable, however, there are several exceptions in that many transition metals (e.g. Cu, Mn) tend to form cations. Most nonmetals (e.g. halogens) tend to accept electrons and form anions.

1. *Cations* have a positive charge. Cations go to *Cathode* in an electrochemical cell.

2. *Anions* have a negative charge. Anions go to *Anode* in an electrochemical cell.

Metals readily lose the electrons when, for example, they dissolve in an aqueous solution to release ions: *Na* forms the Na^+ ion, *Ca* forms the Ca^{2+} ion.

One can predict if an atom will create cation or anion by looking at its position in the periodic table.

Monatomic ions are formed by a single atom (e.g. an atom of Na loses an electron to form an Na^+ ion, an atom of Al loses three electrons to form

[2]See "The Place of Zn, Cd, and Hg in the Periodic Table, William Jensen, Journal of Chemical Education. 80(8).

an Al^{3+} ion etc.) We also have **polyatomic ions** which act as discrete units and are a group of *different* bonded atoms with an overall electrical charge. Common polyatomic anions (listed below) react with hydrogen cations (H^+) to form acidsr:

- acetate: CH_3COO^-, forms: acetic acid (CH_3COOH)
- cyanide: CN^-, forms: hydrocyanic acid (HCN)
- azide: ${N_3}^-$, forms: hydrazoic acid (HN_3)
- carbonate: ${CO_3}^{2-}$, forms: carbonic acid (H_2CO_3)
- nitrate: ${NO_3}^-$, forms: nitric acid (HNO_3)
- nitrite: ${NO_2}^-$, forms: nitrous acid (HNO_2)
- sulfate: ${SO_4}^{2-}$, forms: sulfuric acid (H_2SO_4)
- sulfite: ${SO_3}^{2-}$, forms: sulfurous acid (H_2SO_3)
- phosphate: ${PO_4}^{3-}$, forms: phosphoric acid (H_3PO_4)
- perchlorate: ${ClO_4}^-$, forms: perchloric acid ($HClO_4$)
- chlorate: ${ClO_3}^-$, forms: chloric acid ($HClO_3$)
- chlorite: ${ClO_2}^-$, forms: chlorous acid ($HClO_2$)
- hypochlorite: ClO^-, forms: hypochlorous acid ($HClO$)
- chromate: ${CrO_4}^{2-}$, forms: chromic acid (H_2CrO_4)
- dichromate: ${Cr_2O_7}^{2-}$, forms: dichromic acid ($H_2Cr_2O_7$)
- permanganate: ${MnO_4}^-$, forms: permanganic acid ($HMnO_4$)

When electrons are transferred and ions form, ionic bonds result. **Ionic bonds are electrostatic forces of attraction between particles (ions) bearing opposite charges**.

When electrons are shared and molecules form, molecular or covalent bonds result. **Covalent bonds are forces of attraction between positively charged nuclei of bonded atoms and pair(s) of electrons shared or located between them**.

1.3.1 Ionic Compounds

Ionic compounds form and are held together by the electrostatic attraction between – cations and anions – the oppositely charged ions. The electrostatic attraction is called the *ionic bond*. Typically, a metallic atom loses an electron to form a cation and a nonmetallic atom gains an electron to form an anion. These ions then attract each other forming an ionic compound. This is usually, but not always, true: NaCl and $CaCl_2$ are ionic, but $AlCl_3$ is not. An atom is electrically neutral (i.e. number of positively charged protons = number of negatively charged electrons).

Why would such an electrically neutral atom gain or lose electrons to be electrically charged (when the conditions are right)? One reason is due to quantum chemistry. By gaining or losing the electrons (and thus forming *ions* – the charged particles – in the process) atoms tend to reach the electron configurations of the *nearest noble gas atoms*. This happens because the electrons sort of make a truce and *settle into their groove* by filling the orbitals. This reduces their "excitement" giving them the so-called stability. One might think that a *charged* particle such as an Na^+ ion may be less stable as compared to a chargeless atom like an Na atom. But enough experimental evidence exists to believe that once the orbitals are full, the electrons less easily tend to move from one atom to another. Also, the term "stability" here refers more to the movement across atoms, than to a physical movement of particles. *Electronically stable* ions (since they attain the nearest noble gas configuration) freely move around (for example, in aqueous solutions, where they are supposed to be in a "dissociated" state).

1.3.2 Molecular Compounds

2 Stoichiometry of Chemical Reactions

> Meeting of two personalities is like the contact of two chemical substances; if there is a reaction, both are transformed.
>
> *Carl Jung*

Stoichiometry helps us determine the *quantitative relations* between *reactants* and *products*. This section also describes various common reactions and their types. Conditions also need to be right for the reactions to take place. Balancing reactions in a *chemical equation* (for matter and charge) is also given sufficient treatment.

3 Todo's

Complete this section later

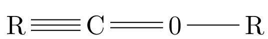
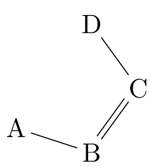
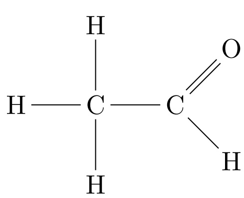
4 Entropy

Entropy is a confusing term. It pays to understand what it means. At his webpage, https://energyandentropy.com/page/index.html, Professor Leff asks several questions that challenge the notion that entropy measures the amount of *disorder* in the system. Unfortunately, the disorder metaphor is usually applied *inconsistently* when explaining entropy. Some counterexamples are also ignored:

- It *appears* that entropy increases with volume. But water provides a counterexample. Water contracts when heated from 0°C to 4°C, however, its numerical entropy increases.
- It is known that the numerical entropy of 2 kg ice is more than that of 1 kg ice. Since it is still ice, how is more *quantity* of ice more *disordered*?

4.1 Energy-entropy Connection

5 Reactions

- 
- 
- 

6 Electronic Structure and Periodic Properties of Elements

Introduction This chapter discusses the *dual nature of light*, the so-called *wave-particle duality*, the electromagnetic radiation (of which visible light is just a short portion) and its relation to the *electronic structure of atoms*. We will also see how electromagnetic radiation can be used to identify elements from thousands of light years away.

6.1 Electromagnetic Energy

Newton, of course, was a towering figure in the development of physics and mathematics. He conducted experiments using a glass prism. Glass prism *separates* the visible (white) light into bands of color. He went on to propose a corpuscular theory of light that asserts that light is made of tiny particles moving according to Newton's laws of motion.

Imagine yourself in late 1700's or early 1800's. To ask questions, carry out careful experiments, and objectively conclude, in the spirit of science, some findings that contradict Newton's reasoning was considered heresy. Still, Francesco Grimaldi, Robert Hooke, Christiaan Huygens, Thomas Young, and Augustin-Jean Fresnel (along with François Arago) helped develop the wave theory of light. One limitation of wave theory of light was that it proposed the need of a medium for the light to travel. This was later superseded by Maxwell in 1860 when he showed how electromagnetic radiation traveled through space that is devoid of any medium. Later, several scientists developed a quantum theory of light which pictures light as comprised of both waves and particles. Wikipedia mentions the following about a progression from particle theory, to wave theory, to electromagnetic theory, and finally (as of 2020) to quantum theory:

> Modern physics sees light as something that can be described sometimes with mathematics appropriate to one type of macroscopic metaphor (particles), and sometimes another macroscopic metaphor (water waves), but is actually something that cannot be fully imagined. As in the case for radio waves and the X-rays involved in Compton scattering, physicists have noted that electromagnetic radiation tends to behave more like a classical wave at lower frequencies, but more like a classical particle at higher frequencies, but never completely loses all qualities of one or the other. Visible light, which occupies a middle ground in frequency, can easily be shown in experiments to be describable using either a wave or particle model, or sometimes both.
>
> *Wikipedia 2020*

Visible light and other forms of electromagnetic radiation play important roles in chemistry, since they can be used to infer the energies of electrons within atoms and molecules. Much of modern technology is based on electromagnetic radiation. For example, radio waves from a mobile phone, X-rays used by dentists, the energy used to cook food in your microwave, the radiant heat from red-hot objects, and the light from your television screen are forms of electromagnetic radiation that all exhibit wavelike behavior.

Add Appendix for Young's Experiment

Take a look at the Wave Theory of Light

Add Appendixes

Waves

6.2 The Bohr Model

6.3 Development of Quantum Theory

6.4 Electronic Structure of Atoms (Electron Configurations)

6.5 Periodic Variations in Element Properties