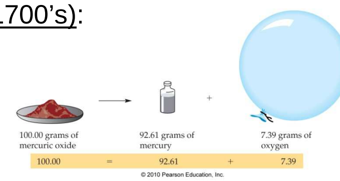
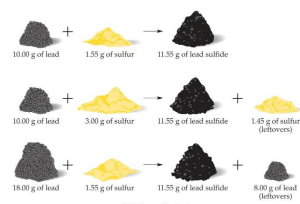
A Sprint Through the Development of Atomic Theory

- Law of Conservation of Mass (Lavoisier, 1700's): mass before rxn = mass after rxn.

"Father of Modern Chemistry… beheaded!

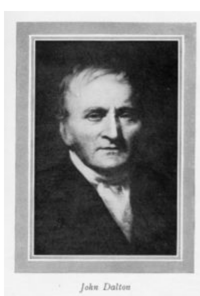


- Law of Definite Proportions (Proust): compound always contains the same elements in the same proportions by mass.



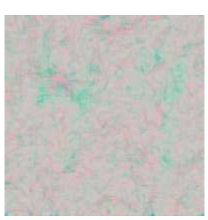
- Law of Multiple Proportions (Dalton): elements may combine in two or more sets of proportions, each a different compound (CO and CO_2)

Dalton's Atomic Theory (~1800):



- Matter is made up of atoms (tiny particles)
- Atoms of the same element are alike, but atoms of one element differ from those of another.
- Compounds form when atoms of elements combine in certain proportions
- During chemical reactions, atoms are rearranged, not changed or destroyed.

TABLE 2.1 Compound	Representation[a]	Mass of N per 1.000 g of O	Ratio of the Masses of N[b]
Nitrous oxide		1.750 g	(1.750 ÷ 0.4375) = 4.000
Nitric oxide		0.8750 g	(0.8750 ÷ 0.4375) = 2.000
Nitrogen dioxide		0.4375 g	(0.4375 ÷ 0.4375) = 1.000



- Also did extensive research on color blindness!

Dalton Got Pretty Close!

- Dalton's theory still is the foundation for our modern understanding of atoms.
  - Some modifications have been necessary.

  1. We now know atoms are composed of smaller particles
  2. We now know that there can be subtle differences in atoms of the same element (isotopes)
  3. We now know of nuclear reactions, in which atoms are broken apart.

- Not bad considering all he had to work with was a balance!

Building Blocks for Atoms: Subatomic Particles

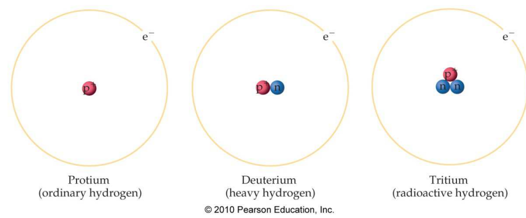
Table 3.2 Subatomic Particles

Particle	Symbol	Mass (u)	Charge	Location in Atom
Proton	p^+	1	1+	Nucleus
Neutron	n	1	0	Nucleus
Electron	e^-	$\frac{1}{1837}$	1−	Outside nucleus

- Number of protons determines the identity of the atom
  - Atomic Number (Z)
- Most of the mass of the atom is in the nucleus
  - Mass Number (A, total number of *nucleons*)
- Typical notation: ${}^{A}_{Z}\text{Element Symbol}$

Building Blocks for Atoms: Subatomic Particles…nucleons

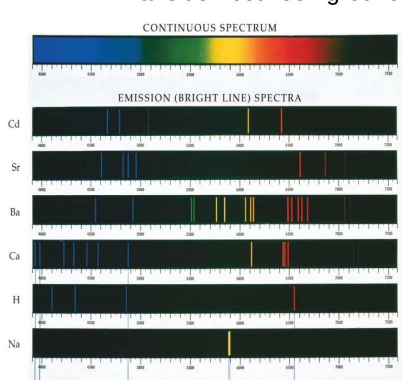
- Isotopes: same number of protons, different number of neutrons
  - Describing Isotopes
  - Carbon-12 = ^{12}C, Uranium-238 = ^{238}U (atomic # may be shown, too).

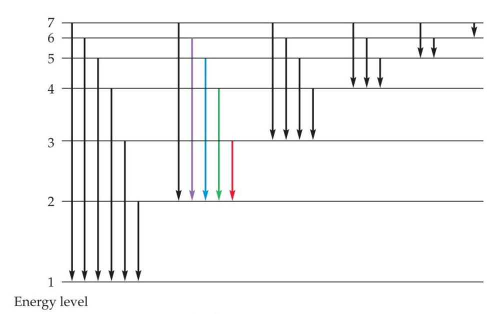


- In a neutral atom, number of protons = number of electrons.
- Much of the chemical reactivity is determined by electronic structure, which is influenced by the nucleus

Building Blocks for Atoms: Subatomic Particles..electrons

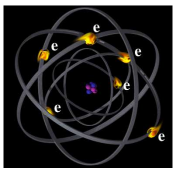
- Several models exist to describe structure and behavior of atoms
- Key consideration is that energy levels are quantized
  - Evidenced by line spectra (figs 3.11 and 3.12)
  - Transition between ground and excited states…energy considerations

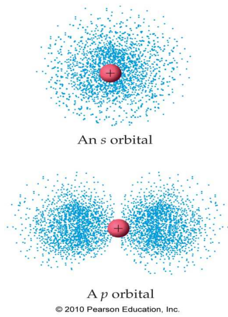


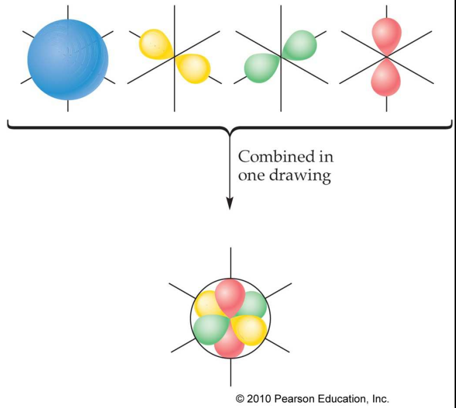


Building Blocks for Atoms: Subatomic Particles...electrons

- Orbits vs orbitals (Figs 3.13 - 3.15)
  - Each orbital can “hold” two electrons







“Categorizing” Orbitals and Electrons

- Electrons in orbitals are described using *quantum numbers*
  - Need 4 to specify a single electron
  - Possible values depend on the atom

n: principle q# - relates to “size” or energy

ℓ: angular momentum q# - relates to shape.

$\ell = 0 \ldots n-1$

m_ℓ: magnetic q# - relates to orientation.

$m_\ell = -\ell \ldots 0 \ldots +\ell$

m_s: spin q# - +1/2 or -1/2

n	ℓ	m_ℓ
1	0 (s)	0
2	0 (s)	0
	1 (p)	-1, 0, 1
3	0 (s)	0
	1 (p)	-1, 0, 1
	2 (d)	-2, -1, 0, 1, 2
4	0 (s)	0
	1 (p)	-1, 0, 1
	2 (d)	-2, -1, 0, 1, 2
	3 (f)	-3, -2, -1, 0, 1, 2, 3

- Pictures of orbital shapes:
  - http://www.orbitals.com/orb/
  - https://en.wikipedia.org/wiki/Atomic_orbital#Orbitals_table
  - http://winter.group.shef.ac.uk/orbitron/ (requires Adobe flash)

Filling up Orbitals

- Predictable order for orbital filling (mostly)
  - Increasing n+ℓ, smallest n first

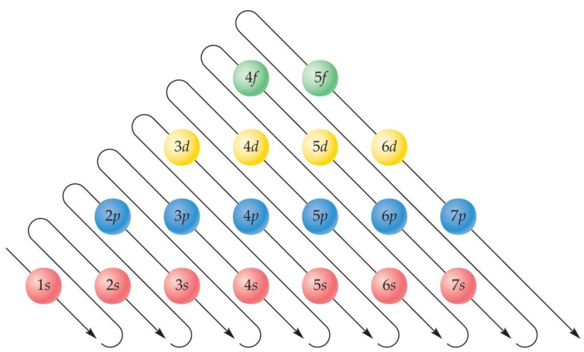


Table 3.3 Electron Structures for Atoms of the First 20 Elements

Name	Atomic Number	Electron Structure
Hydrogen	1	$1s^1$
Helium	2	$1s^2$
Lithium	3	$1s^2 2s^1$
Beryllium	4	$1s^2 2s^2$
Boron	5	$1s^2 2s^2 2p^1$
Carbon	6	$1s^2 2s^2 2p^2$
Nitrogen	7	$1s^2 2s^2 2p^3$
Oxygen	8	$1s^2 2s^2 2p^4$
Fluorine	9	$1s^2 2s^2 2p^5$
Neon	10	$1s^2 2s^2 2p^6$
Sodium	11	$1s^2 2s^2 2p^6 3s^1$
Magnesium	12	$1s^2 2s^2 2p^6 3s^2$
Aluminum	13	$1s^2 2s^2 2p^6 3s^2 3p^1$
Silicon	14	$1s^2 2s^2 2p^6 3s^2 3p^2$
Phosphorus	15	$1s^2 2s^2 2p^6 3s^2 3p^3$
Sulfur	16	$1s^2 2s^2 2p^6 3s^2 3p^4$
Chlorine	17	$1s^2 2s^2 2p^6 3s^2 3p^5$
Argon	18	$1s^2 2s^2 2p^6 3s^2 3p^6$
Potassium	19	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
Calcium	20	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

Filling up Orbitals

Atomic number	Symbol	Electron configuration	Atomic number	Symbol	Electron configuration	Atomic number	Symbol	Electron configuration
1	H	$1s^1$	37	Rb	[Kr]$5s^1$	73	Ta	[Xe]$6s^2 4f^{14} 5d^3$
2	He	$1s^2$	38	Sr	[Kr]$5s^2$	74	W	[Xe]$6s^2 4f^{14} 5d^4$
3	Li	[He]$2s^1$	39	Y	[Kr]$5s^2 4d^1$	75	Re	[Xe]$6s^2 4f^{14} 5d^5$
4	Be	[He]$2s^2$	40	Zr	[Kr]$5s^2 4d^2$	76	Os	[Xe]$6s^2 4f^{14} 5d^6$
5	B	[He]$2s^2 2p^1$	41	Nb	[Kr]$5s^1 4d^4$	77	Ir	[Xe]$6s^2 4f^{14} 5d^7$
6	C	[He]$2s^2 2p^2$	42	Mo	[Kr]$5s^1 4d^5$	78	Pt	[Xe]$6s^1 4f^{14} 5d^9$
7	N	[He]$2s^2 2p^3$	43	Tc	[Kr]$5s^2 4d^5$	79	Au	[Xe]$6s^1 4f^{14} 5d^{10}$
8	O	[He]$2s^2 2p^4$	44	Ru	[Kr]$5s^1 4d^7$	80	Hg	[Xe]$6s^2 4f^{14} 5d^{10}$
9	F	[He]$2s^2 2p^5$	45	Rh	[Kr]$5s^1 4d^8$	81	Tl	[Xe]$6s^2 4f^{14} 5d^{10} 6p^1$
10	Ne	[He]$2s^2 2p^6$	46	Pd	[Kr]$4d^{10}$	82	Pb	[Xe]$6s^2 4f^{14} 5d^{10} 6p^2$
11	Na	[Ne]$3s^1$	47	Ag	[Kr]$5s^1 4d^{10}$	83	Bi	[Xe]$6s^2 4f^{14} 5d^{10} 6p^3$
12	Mg	[Ne]$3s^2$	48	Cd	[Kr]$5s^2 4d^{10}$	84	Po	[Xe]$6s^2 4f^{14} 5d^{10} 6p^4$
13	Al	[Ne]$3s^2 3p^1$	49	In	[Kr]$5s^2 4d^{10} 5p^1$	85	At	[Xe]$6s^2 4f^{14} 5d^{10} 6p^5$
14	Si	[Ne]$3s^2 3p^2$	50	Sn	[Kr]$5s^2 4d^{10} 5p^2$	86	Rn	[Xe]$6s^2 4f^{14} 5d^{10} 6p^6$
15	P	[Ne]$3s^2 3p^3$	51	Sb	[Kr]$5s^2 4d^{10} 5p^3$	87	Fr	[Rn]$7s^1$
16	S	[Ne]$3s^2 3p^4$	52	Te	[Kr]$5s^2 4d^{10} 5p^4$	88	Ra	[Rn]$7s^2$
17	Cl	[Ne]$3s^2 3p^5$	53	I	[Kr]$5s^2 4d^{10} 5p^5$	89	Ac	[Rn]$7s^2 6d^1$
18	Ar	[Ne]$3s^2 3p^6$	54	Xe	[Kr]$5s^2 4d^{10} 5p^6$	90	Th	[Rn]$7s^2 6d^2$
19	K	[Ar]$4s^1$	55	Cs	[Xe]$6s^1$	91	Pa	[Rn]$7s^2 5f^2 6d^1$
20	Ca	[Ar]$4s^2$	56	Ba	[Xe]$6s^2$	92	U	[Rn]$7s^2 5f^3 6d^1$
21	Sc	[Ar]$4s^2 3d^1$	57	La	[Xe]$6s^2 5d^1$	93	Np	[Rn]$7s^2 5f^4 6d^1$
22	Ti	[Ar]$4s^2 3d^2$	58	Ce	[Xe]$6s^2 4f^1 5d^1$	94	Pu	[Rn]$7s^2 5f^6$
23	V	[Ar]$4s^2 3d^3$	59	Pr	[Xe]$6s^2 4f^3$	95	Am	[Rn]$7s^2 5f^7$
24	Cr	[Ar]$4s^1 3d^5$	60	Nd	[Xe]$6s^2 4f^4$	96	Cm	[Rn]$7s^2 5f^7 6d^1$
25	Mn	[Ar]$4s^2 3d^5$	61	Pm	[Xe]$6s^2 4f^5$	97	Bk	[Rn]$7s^2 5f^9$
26	Fe	[Ar]$4s^2 3d^6$	62	Sm	[Xe]$6s^2 4f^6$	98	Cf	[Rn]$7s^2 5f^{10}$
27	Co	[Ar]$4s^2 3d^7$	63	Eu	[Xe]$6s^2 4f^7$	99	Es	[Rn]$7s^2 5f^{11}$
28	Ni	[Ar]$4s^2 3d^8$	64	Gd	[Xe]$6s^2 4f^7 5d^1$	100	Fm	[Rn]$7s^2 5f^{12}$
29	Cu	[Ar]$4s^1 3d^{10}$	65	Tb	[Xe]$6s^2 4f^9$	101	Md	[Rn]$7s^2 5f^{13}$
30	Zn	[Ar]$4s^2 3d^{10}$	66	Dy	[Xe]$6s^2 4f^{10}$	102	No	[Rn]$7s^2 5f^{14}$
31	Ga	[Ar]$4s^2 3d^{10} 4p^1$	67	Ho	[Xe]$6s^2 4f^{11}$	103	Lr	[Rn]$7s^2 5f^{14} 6d^1$
32	Ge	[Ar]$4s^2 3d^{10} 4p^2$	68	Er	[Xe]$6s^2 4f^{12}$	104	Rf	[Rn]$7s^2 5f^{14} 6d^2$
33	As	[Ar]$4s^2 3d^{10} 4p^3$	69	Tm	[Xe]$6s^2 4f^{13}$	105	Db	[Rn]$7s^2 5f^{14} 6d^3$
34	Se	[Ar]$4s^2 3d^{10} 4p^4$	70	Yb	[Xe]$6s^2 4f^{14}$	106	Sg	[Rn]$7s^2 5f^{14} 6d^4$
35	Br	[Ar]$4s^2 3d^{10} 4p^5$	71	Lu	[Xe]$6s^2 4f^{14} 5d^1$	107	Bh	[Rn]$7s^2 5f^{14} 6d^5$
36	Kr	[Ar]$4s^2 3d^{10} 4p^6$	72	Hf	[Xe]$6s^2 4f^{14} 5d^2$	108	Hs	[Rn]$7s^2 5f^{14} 6d^6$
						109	Mt	[Rn]$7s^2 5f^{14} 6d^7$
						110	Ds	[Rn]$7s^1 5f^{14} 6d^9$
						111	Rg	[Rn]$7s^1 5f^{14} 6d^{10}$

https://chem.libretexts.org/@api/deki/files/54781/electron_config.jpg?revision=1

Cataloging Elements in the Periodic Table

- Table is arranged based on atomic structure/configuration
  - Vertical columns or **Groups** (or family): Element have similar chemical properties within a group
    - Mostly due to electron configuration and valence electronic structure
  - Horizontal rows or **Periods**: Properties vary across a period
- Similarities in atomic structure lead to similarities in reactivity.
- Information found in periodic table (at a minimum)
  - Symbol
  - Atomic number
  - Atomic Mass: weighted average of all isotopes compared to carbon-12

Cataloging Elements in the Periodic Table