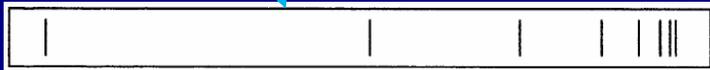
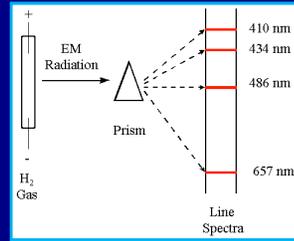


The Electronic Structure of the Atom

- Bohr based his theory on his experiments with hydrogen
- he found that when energy is added to a sample of hydrogen, energy is absorbed and reemitted as light
- When passed through a prism, a "line spectrum" is obtained



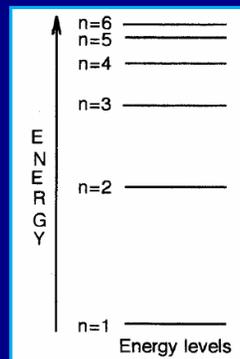
Bohr's Explanation:



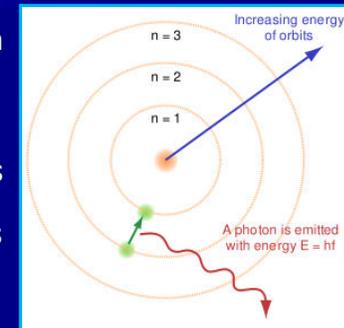
- The electron in hydrogen can only exist in specific energy states.
- These energy states are associated with specific **circular orbits** which the electron can occupy around the atom.
- When an electron absorbs energy, it moves from one orbit to another.
- The greater the energy, the farther the orbit is from the nucleus.

Energy Levels of Hydrogen:

- Energy Level/Orbit:** the specific amount of energy of an electron in an atom
- The energy levels of hydrogen have the pattern shown ("n" is the number of the energy level)



- The **line spectrum** represents energy level differences occurring when an electron gives off energy by dropping from a high energy level to a lower one.
- Since there are specific energy levels the electrons can be in, there are only certain energy differences that occur
- The difference between two different energy levels is called a **QUANTUM** of energy



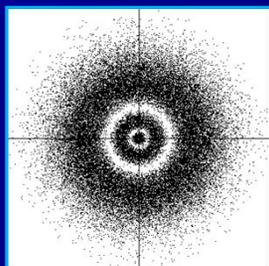
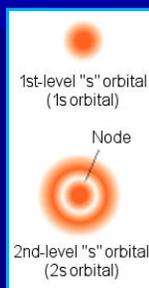
The Refined Theory:

- after Bohr published his theories, several changes were made to his ideas.
- It was discovered that electrons don't travel in circular orbits!
- Instead, different electrons, depending on their energies, occupy particular regions of space called "orbitals".
- **ORBITAL:**
 - The actual region of space occupied by an electron in a particular energy level (based on probability of where an electron could be found)
 - **Each orbital can hold up to 2 electrons!**

Some Terminology:

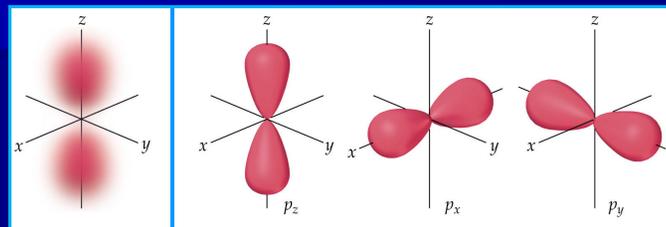
- There are 4 types of orbitals that we discuss:
 - "s", "p", "d", and "f"
- **Shell:** the set of orbitals having the same "n" value
 - Ex. 3rd shell is made up of the 3s, 3p, and 3d orbitals
- **Subshell:** a set of orbitals of the same type
 - Ex. There are 3 "p" orbitals in the 2p subshell

Orbital Types and Shapes: "s orbitals"



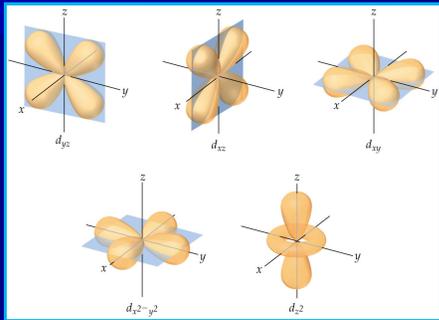
- In general, "s orbitals" are considered spherical
- There is only 1 s orbital in an s subshell
- ∴ an "s" subshell can hold 2 electrons

"p orbitals"



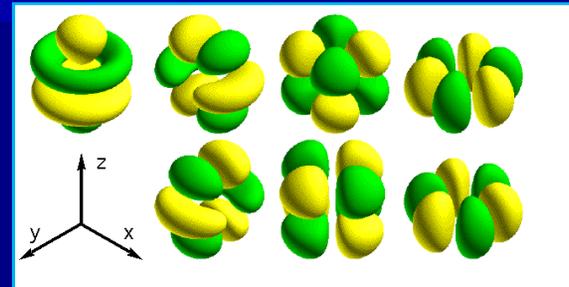
- Think balloon shapes!
- There are 3 "p" orbitals in every "p" subshell
- ∴ a "p" subshell can hold 6 electrons

"d orbitals"



- There are 5 "d" orbitals in every "d" subshell
- ∴ a "d" subshell can hold 10 electrons

"f orbitals"



- There are 7 "f" orbitals in every "f" subshell
- ∴ an "f" subshell can hold 14 electrons

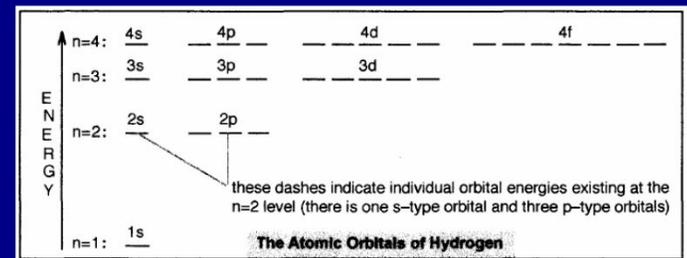
Rules governing which types of orbitals can occur:

- For a given value of "n", n different types of orbitals are possible
- For n=1: only the s-type is possible
- For n=2: the s- and p-types are possible
- For n=3: the s-, p-, and d-types are possible
- For n=4: the s-, p-, d-, and f-types are possible.

- These rules come from the mathematical solutions for Schrödinger's wave equation

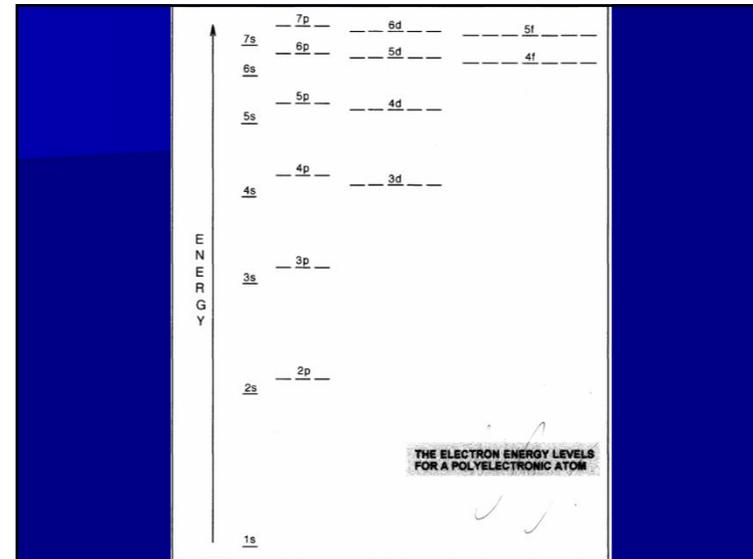
Energy Level Diagrams:

- Diagram showing the relative energy levels of all of the orbitals in the atom/ion
- Shown for hydrogen below:



Energy Level Diagram for Polyelectronic Atom

- Repulsion between electrons changes the energy of the different types of orbitals
- A new energy level diagram must be drawn that works for all atoms with more than 1 electron



- 3 rules govern the order the orbitals are filled:

– Aufbau Principal:

- As atomic number increases, electrons are added to the available orbitals. To ensure lowest possible energy (**ground state**) for the atom, electrons are added to the **LOWEST ENERGY ORBITALS FIRST**.

– Pauli Exclusion Principle:

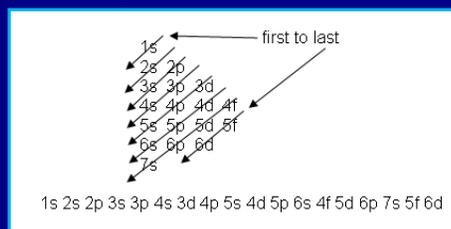
- A maximum of TWO electrons can be placed in each orbital.

– Hund's Rule:

- When electrons occupy subshells of equal energy, they must be singly occupied with electrons having parallel spins. 2nd electrons are then added to each subshell so each electron has opposite spin.

Energy Level Diagram Practice:

- Draw energy level diagrams for the following atoms:
 - Si, Tc, Ca, Zr, Ga
- Note: there is a trick to determining the order to fill orbitals without doing the full electron configuration



Electron Configurations:

- represents the orbitals that are occupied in an atom/ion and how many electrons are in each subshell
- like a simplified energy level diagram

Writing Electron Configurations for Neutral Atoms:

- The electron configuration of most elements can be easily determined by using the "orbital version" of the periodic table

1	2											3	4	5	6	7	8	9	10																									
H Hydrogen 1.00794	He Helium 4.002602											B Boron 10.811	C Carbon 12.011	N Nitrogen 14.0067	O Oxygen 15.9994	F Fluorine 18.998403	Ne Neon 20.1797																											
3	4											11	12											19	20	21	22	23	24	25	26	27	28	29	30									
Li Lithium 6.941	Be Beryllium 9.012182											Na Sodium 22.98976928	Mg Magnesium 24.304											K Potassium 39.0983	Ca Calcium 40.078	Sc Scandium 44.955912	Ti Titanium 47.88	V Vanadium 50.9415	Cr Chromium 51.9961	Mn Manganese 54.938044	Fe Iron 55.847	Co Cobalt 58.9332	Ni Nickel 58.6934	Cu Copper 63.546	Zn Zinc 65.38	Ga Gallium 69.723	Ge Germanium 72.64	As Arsenic 74.9216	Se Selenium 78.96	Br Bromine 79.904	Kr Krypton 83.80			
11	12	13	14	15	16	17	18											37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54									
Na Sodium 22.98976928	Mg Magnesium 24.304	Al Aluminum 26.9815386	Si Silicon 28.0855	P Phosphorus 30.973762	S Sulfur 32.06	Cl Chlorine 35.453	Ar Argon 39.948											Rb Rubidium 85.4678	Sr Strontium 87.62	Y Yttrium 88.905848	Zr Zirconium 91.224	Nb Niobium 92.90638	Mo Molybdenum 95.94	Tc Technetium 98	Ru Ruthenium 101.07	Rh Rhodium 102.9055	Pd Palladium 106.42	Ag Silver 107.8682	Cd Cadmium 112.411	In Indium 114.818	Sn Tin 118.710	Sb Antimony 121.757	Te Tellurium 127.60	I Iodine 126.9045	Xe Xenon 131.29									
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36											55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	
K Potassium 39.0983	Ca Calcium 40.078	Sc Scandium 44.955912	Ti Titanium 47.88	V Vanadium 50.9415	Cr Chromium 51.9961	Mn Manganese 54.938044	Fe Iron 55.847	Co Cobalt 58.9332	Ni Nickel 58.6934	Cu Copper 63.546	Zn Zinc 65.38	Ga Gallium 69.723	Ge Germanium 72.64	As Arsenic 74.9216	Se Selenium 78.96	Br Bromine 79.904	Kr Krypton 83.80											Cs Cesium 132.90545	Ba Barium 137.327	La Lanthanum 138.90547	Ce Cerium 140.12	Pr Praseodymium 140.90768	Nd Neodymium 144.24	Pm Promethium 145	Sm Samarium 150.36	Eu Europium 151.964	Gd Gadolinium 157.25	Tb Terbium 158.92534	Dy Dysprosium 162.50	Ho Holmium 164.93032	Er Erbium 167.26	Tm Thulium 168.934	Yb Ytterbium 173.054	Lu Lutetium 174.967
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54											87	88	89	90	91	92	93	94	95	96	97	98	99	100			
Rb Rubidium 85.4678	Sr Strontium 87.62	Y Yttrium 88.905848	Zr Zirconium 91.224	Nb Niobium 92.90638	Mo Molybdenum 95.94	Tc Technetium 98	Ru Ruthenium 101.07	Rh Rhodium 102.9055	Pd Palladium 106.42	Ag Silver 107.8682	Cd Cadmium 112.411	In Indium 114.818	Sn Tin 118.710	Sb Antimony 121.757	Te Tellurium 127.60	I Iodine 126.9045	Xe Xenon 131.29											Ra Radium 226	Ac Actinium 227	Th Thorium 232.0377	Pa Protactinium 231.03688	U Uranium 238.02891	Np Neptunium 237.048173	Pu Plutonium 244	Am Americium 243	Cm Curium 247	Bk Berkelium 247	Cf Californium 251	Es Einsteinium 252	Fm Fermium 257	Md Mendelevium 258	No Nobelium 259		
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90									
Cs Cesium 132.90545	Ba Barium 137.327	La Lanthanum 138.90547	Ce Cerium 140.12	Pr Praseodymium 140.90768	Nd Neodymium 144.24	Pm Promethium 145	Sm Samarium 150.36	Eu Europium 151.964	Gd Gadolinium 157.25	Tb Terbium 158.92534	Dy Dysprosium 162.50	Ho Holmium 164.93032	Er Erbium 167.26	Tm Thulium 168.934	Yb Ytterbium 173.054	Lu Lutetium 174.967	Hf Hafnium 178.49	Ta Tantalum 180.94788	W Tungsten 183.85	Re Rhenium 186.207	Os Osmium 190.2	Ir Iridium 192.22	Pt Platinum 195.08	Au Gold 196.966569	Hg Mercury 200.59	Tl Thallium 204.3833	Pb Lead 207.2	Bi Bismuth 208.9804	Po Polonium 209	At Astatine 210	Rn Radon 222													
87	88	89	90	91	92	93	94	95	96	97	98	99	100											101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118			
Ra Radium 226	Ac Actinium 227	Th Thorium 232.0377	Pa Protactinium 231.03688	U Uranium 238.02891	Np Neptunium 237.048173	Pu Plutonium 244	Am Americium 243	Cm Curium 247	Bk Berkelium 247	Cf Californium 251	Es Einsteinium 252	Fm Fermium 257	Md Mendelevium 258	No Nobelium 259	Lr Lawrencium 260	104 Rutherfordium 261	105 Dubnium 262	106 Seaborgium 263	107 Bohrium 264	108 Hassium 265	109 Meitnerium 266	110 Darmstadtium 267	111 Roentgenium 268	112 Copernicium 269	113 Nihonium 270	114 Flerovium 271	115 Moscovium 272	116 Livermorium 273	117 Tennessine 274	118 Oganesson 276														

Examples:

- Hydrogen:
 - $1s^1$
- Helium:
 - $1s^2$
- Lithium:
 - $1s^2 2s^1$
- Beryllium:
 - $1s^2 2s^2$
- Boron:
 - $1s^2 2s^2 2p^1$
- And so on...
 - Be: $1s^2 2s^2$
 - B: $1s^2 2s^2 2p^1$
 - C: $1s^2 2s^2 2p^2$
 - N: $1s^2 2s^2 2p^3$
 - O: $1s^2 2s^2 2p^4$
 - F: $1s^2 2s^2 2p^5$
 - Ne: $1s^2 2s^2 2p^6$

Practice Time:

- Predict the electron configuration of the following:
- Si:
 - $1s^2 2s^2 2p^6 3s^2 3p^2$
- Tc:
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^5$
- Ca:
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- Zr:
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^2$
- Ga:
 - $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^1$

Core Notation



- The electrons belonging to an atom can be broken into two subsets:
 1. The CORE electrons.
 2. The OUTER electrons.
- The CORE of an atom is the set of electrons with the configuration of the nearest noble gas having an atomic number LESS than that of the atom being considered.
- The OUTER electrons are all those outside the core. Since the core electrons are not involved in chemical reactions, they are excluded from the electron configuration.

Examples:

- Al: $[\text{Ne}] 3s^2 3p^1$
- You try for...
 - Zr, Ga, Co
- Answers:
 - Zr: $[\text{Kr}] 5s^2 4d^2$
 - Ga: $[\text{Ar}] 4s^2 3d^{10} 4p^1$
 - Co: $[\text{Ar}] 4s^2 3d^7$



- Two exceptions to the configurations of elements up to Kr:
 - Cr: $[\text{Ar}] 4s^2 3d^4$ "3d⁴" is actually $[\text{Ar}] 4s^1 3d^5$
 - Cu: $[\text{Ar}] 4s^2 3d^9$ "3d⁹" is actually $[\text{Ar}] 4s^1 3d^{10}$

A filled or exactly half filled d-subshell is especially stable.

- Because of this extra stability, an atom or ion that is one e^- short of a "d⁵" or "d¹⁰" configuration will shift an e^- from the s- subshell having the highest energy into the unfilled d- subshell.

Writing Electron Configurations for Ions

■ For Negative Ions: (anions)

– Add electrons to the last unfilled subshell, starting where the neutral atom left off.

■ For Example:

– O: [He] 2s² 2p⁶

– P: [Ne] 3s² 3p⁶

For Positive Ions: (cations)

2 Rules to follow:

1. Electrons in the outermost shells (largest n value) are removed first.
2. If there are electrons in both the s and p orbitals of the outermost shell, the electrons in the p orbitals are removed first.

BEFORE

BEFORE

- Outermost electrons are removed preferentially since they are the least attracted to the nucleus

Examples:



Predicting the Number of Valence Electrons

■ Valence Electrons:

– Electrons that can take place in chemical reactions.

– Are all the electrons in the atom **EXCEPT**:

- Core electrons.
- filled d- or f- subshells of electrons.



Examples:

- Al: [Ne] $3s^2 3p^1$ has 3 valence electrons:
Just " $3s^2 3p^1$ "
- Ga: [Ar] $4s^2 3d^{10} 4p^1$ has 3 valence electrons:
Omit " $3d^{10}$ " b/c filled
- Pb: [Xe] $6s^2 4f^{14} 5d^{10} 6p^2$ has 4 valence electrons:
Omit " $4f^{14}$ " and " $5d^{10}$ " b/c filled
- Xe: [Kr] $5s^2 4d^{10} 5p^6$ has ZERO valence electrons:
Noble gas configuration

Homework:

- Complete the Electron Configuration Worksheet