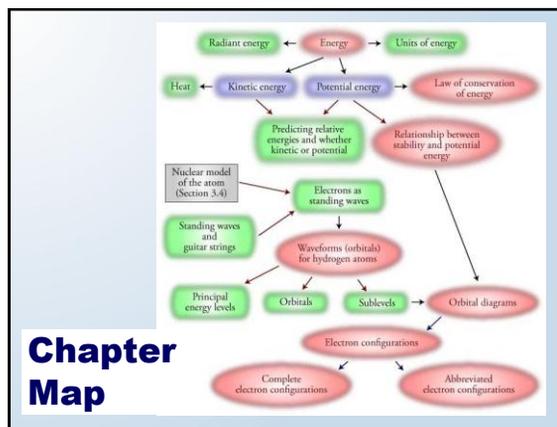
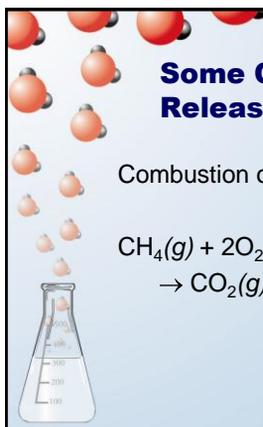




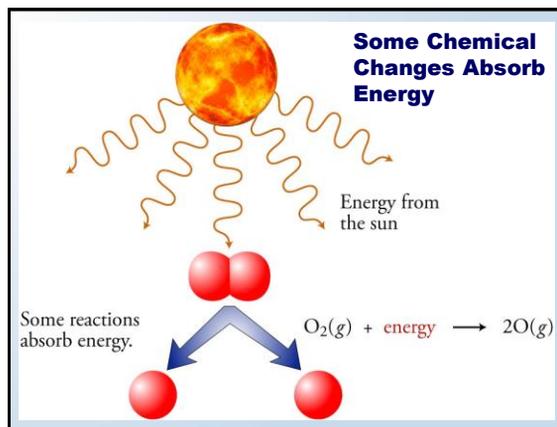
Chapter 4

Modern Atomic Theory

Some Chemical Changes Release Energy

Combustion of Methane

$$\text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l) + \text{Energy}$$


Some Chemical Changes Absorb Energy

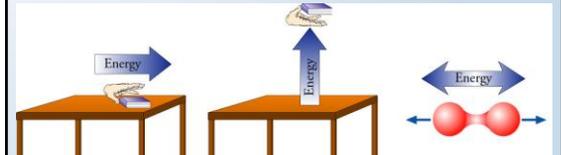
Energy from the sun

Some reactions absorb energy.

$$\text{O}_2(g) + \text{energy} \rightarrow 2\text{O}(g)$$

Energy Terms

- **Energy** = the capacity to do work
- **Work**, in this context, may be defined as what is done to move an object against some sort of resistance.



Energy is required to push a book across a table and overcome the resistance to movement due to friction.

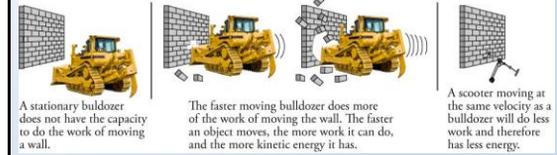
Energy is required to lift a book and overcome the resistance to movement due to gravity.

Energy is required to separate two atoms in a molecule and overcome the resistance to movement due to the chemical bond between them.

Two Types of Energy

- **Kinetic Energy** = the energy of motion

$$= \frac{1}{2} m\mu^2$$



A stationary bulldozer does not have the capacity to do the work of moving a wall.

The faster moving bulldozer does more of the work of moving the wall. The faster an object moves, the more work it can do, and the more kinetic energy it has.

A scooter moving at the same velocity as a bulldozer will do less work and therefore has less energy.

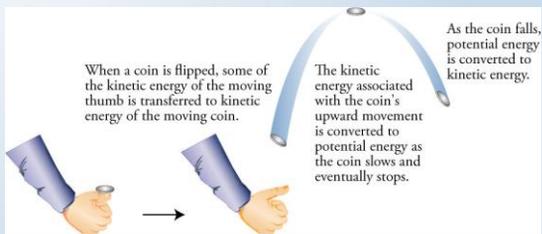
- **Potential Energy** = energy by virtue of position or state

Law of Conservation of Energy

When a coin is flipped, some of the kinetic energy of the moving thumb is transferred to kinetic energy of the moving coin.

The kinetic energy associated with the coin's upward movement is converted to potential energy as the coin slows and eventually stops.

As the coin falls, potential energy is converted to kinetic energy.



Endergonic Change

more stable + energy \rightarrow less stable system

lesser capacity to do work + energy \rightarrow greater capacity to do work

lower PE + energy \rightarrow higher PE

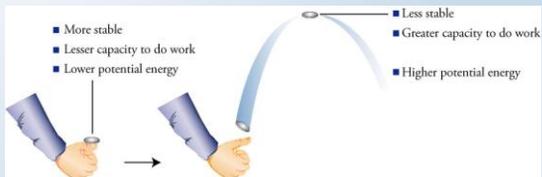
coin in hand + energy \rightarrow coin in air above hand



Coin and Potential Energy

- More stable
- Lesser capacity to do work
- Lower potential energy

- Less stable
- Greater capacity to do work
- Higher potential energy



Bond Breaking and Potential Energy

atoms in bond + Energy \rightarrow separate atoms

more stable + Energy \rightarrow less stable

lower PE + Energy \rightarrow higher PE

$O_2(g)$ + energy \rightarrow $2O(g)$



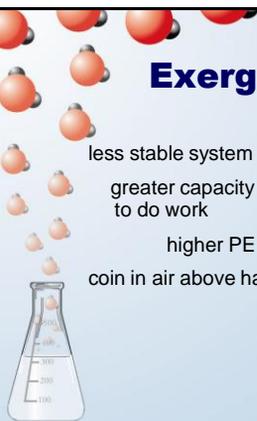
Exergonic Change

less stable system \rightarrow more stable + energy

greater capacity to do work \rightarrow lesser capacity to do work + energy

higher PE \rightarrow lower PE + energy

coin in air above hand \rightarrow coin on ground + energy



Bond Making and Potential Energy

separate atoms \rightarrow atoms in bond + Energy

less stable \rightarrow more stable + Energy

higher PE \rightarrow lower PE + Energy

$O(g) + O_2(g) \rightarrow O_3(g) + \text{energy}$



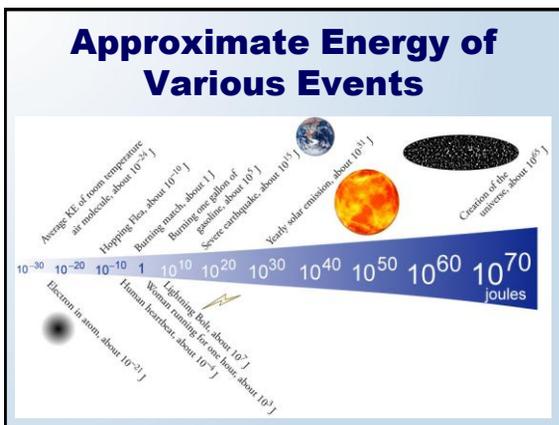
Which higher energy? Is it kinetic or potential?

- 428 m/s Ar atoms or 456 m/s Ar atoms?
- 428 m/s Ar atoms or 428 m/s Kr atoms?
- Na⁺ close to Cl⁻ or Na⁺ and Cl⁻ far apart?
- ROOR or 2 RO
- H(g) and O₂(g) or HO₂(g)
- Solid CO₂ or gaseous CO₂



Units of Energy

- Joule (J) = $\frac{\text{kg m}^2}{\text{s}^2}$
- 4.184 J = 1 cal
- 4.184 kJ = 1 kcal
- 4184 J = 1 Cal (dietary calorie)
- 4.184 kJ = 1 Cal

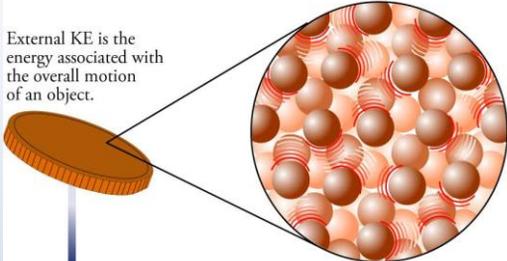
More Terms

- **External Kinetic Energy** = Kinetic energy associated with the overall movement of a body
- **Internal Kinetic Energy** = Kinetic energy associated with the random motion of the particles within a body



External and Internal Kinetic Energy

External KE is the energy associated with the overall motion of an object.



Internal KE is the energy associated with the random motion of particles within an object.

Heat

- **Heat** = Energy transfer from a region of higher temperature to a region of lower temperature due to collisions of particles.



Heat Transfer

Lower-temperature object
↓
Lower average force of collisions
↓
Particles speed up when they collide with particles of the higher-temperature object.
↓
Increased energy

Higher-temperature object
↓
Higher average force of collisions
↓
Particles slow down when they collide with particles of the lower-temperature object.
↓
Decreased energy

Radiant Energy

- Radiant Energy is electromagnetic energy that behaves like a stream of particles.
- It has a dual Nature
 - Particle
 - photons = tiny packets of radiant energy
 - 10^{17} photons/second from a flashlight bulb
 - Wave
 - oscillating electric and magnetic fields
 - describes effect on space, not true nature of radiant energy

A Light Wave's Electric and Magnetic Fields

Source

Wavelength, λ , the distance between two peaks

Electric field, perpendicular to magnetic field

Magnetic field, perpendicular to electric field

Radiant energy

Radiant Energy Spectrum

Photon Energy (J)	Wavelength (m)	Region	Characteristics/Uses
10^{-12} to 10^{-14}	10^{-14} to 10^{-12}	gamma rays	from radioactive decay
10^{-16} to 10^{-18}	10^{-10} to 10^{-8}	x-rays	used for medical and dental x-rays
10^{-18} to 10^{-20}	10^{-8} to 10^{-7}	ultraviolet (UV) visible	causes tanning, skin cancer, genetic damage
10^{-20} to 10^{-22}	10^{-7} to 10^{-6}	infrared (IR)	released when bodies cool
10^{-24} to 10^{-26}	10^{-3} to 10^{-1}	microwaves	used for microwave ovens, radar, and space vehicle communication
10^{-28} to 10^{-30}	10^0 to 10^2	television and radiowaves	used for communication and entertainment

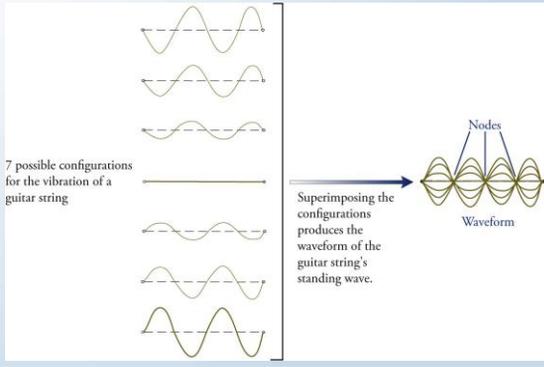
Atomic Theory

- *To see a World in a Grain of Sand
And a Heaven in a Wild Flower
Hold Infinity in the palm of your hand
And Eternity in an hour*
William Blake Auguries of Innocence
- *Thus, the task is not so much to see what
no one has yet seen, but to think what
nobody has yet thought, about that which
everybody sees.*
Erwin Schrodinger

Ways to deal with Complexity and Uncertainty

- **Analogies** In order to communicate something of the nature of the electron, scientists often use analogies. For example, in some ways, electrons are *like* vibrating guitar strings.
- **Probabilities** In order to accommodate the uncertainty of the electron's position and motion, we refer to where the electron *probably* is within the atom instead of where it definitely is.

Guitar String Waveform



Wave Character of the Electron

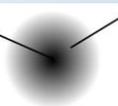
- Just as the intensity of the movement of a guitar string can vary, so can the intensity of the negative charge of the electron vary at different positions outside the nucleus.
- The variation in the intensity of the electron charge can be described in terms of a three-dimensional standing wave *like* the standing wave of the guitar string.

Wave Character of the Electron

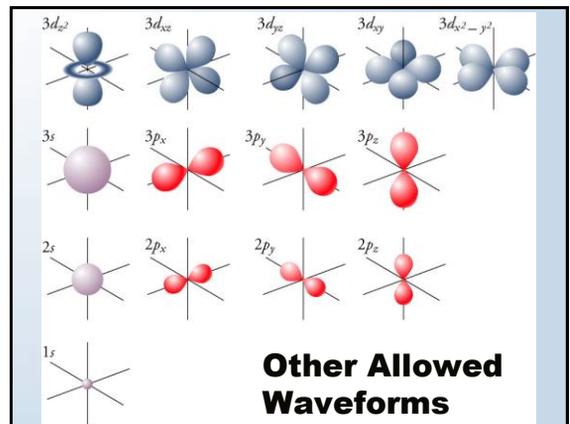
- Although both the electron and the guitar string can have an infinite number of possible waveforms, only certain waveforms are possible.
- We can focus our attention on the waveform of varying charge intensity without having to think about the actual physical nature of the electron.

Waveform for 1s Electron

Nucleus, about 0.000001 the diameter of the atom

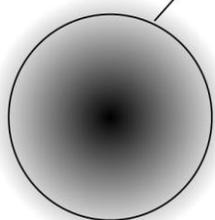


The negative charge is most intense at the nucleus and decreases in intensity with distance outward.

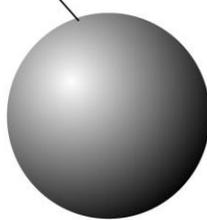


1s Orbital

Almost all of the electron's charge lies within a spherical shell with the diameter of this circle.

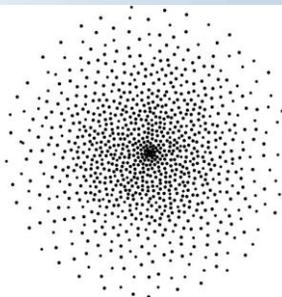


Sphere enclosing almost all of the electron's negative charge



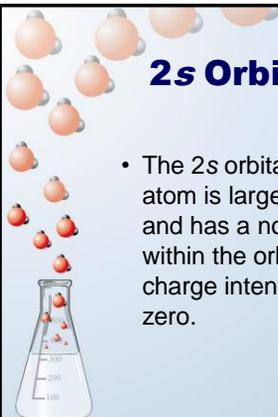
Particle Interpretation of 1s Orbital

A multiple exposure picture of the electron in a 1s orbital of a hydrogen atom might look like this.

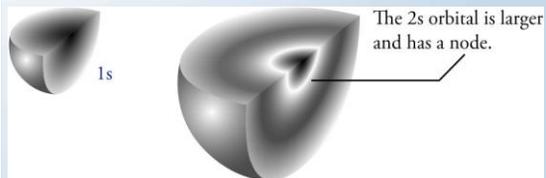


2s Orbital

- The 2s orbital for a hydrogen atom is larger than the 1s orbital and has a node, which is a region within the orbital where the charge intensity decreases to zero.

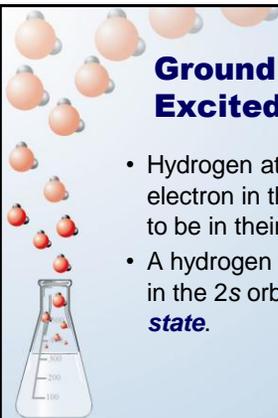


Cutaway of 1s and 2s Orbitals

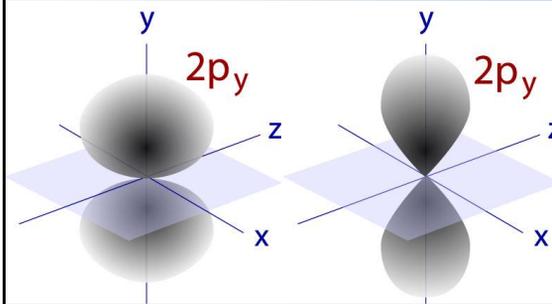


Ground State and Excited State

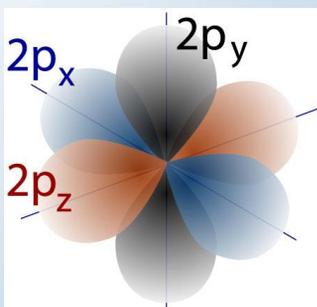
- Hydrogen atoms with their electron in the 1s orbital are said to be in their **ground state**.
- A hydrogen atom with its electron in the 2s orbital is in an **excited state**.



Realistic and Stylized 2p_y Orbital

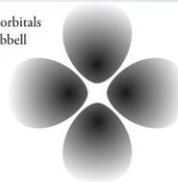


2p_x, 2p_y, and 2p_z Orbitals

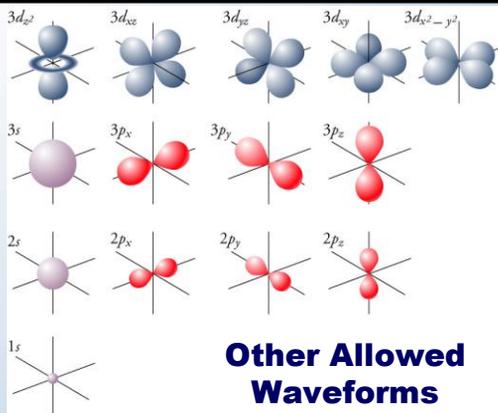
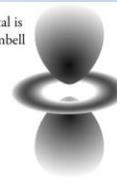


3d Orbitals

Four of the five 3d orbitals have a double dumbbell shape like this one.



The fifth 3d orbital is shaped like a dumbbell and a donut.



Sublevels

- Orbitals that have the same potential energy, the same size, and the same shape are in the same **sublevel**.
- The sublevels are sometimes called **subshells**.

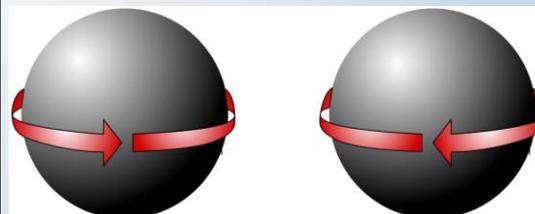


Orbitals for Ground States of Known Elements

7s	7p	---	---	---
6s	6p	---	6d	-----
5s	5p	---	5d	-----
4s	4p	---	4d	-----
3s	3p	---	3d	-----
2s	2p	---		
1s				

No other orbitals are necessary for describing the electrons of the known elements in their ground states.

Electron Spin



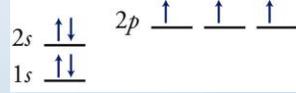
Pauli Exclusion Principle

- No two electrons in an atom can be the same in all ways.
- There are four ways that electrons can be the same:
 - Electrons can be in the same principal energy level.
 - They can be in the same sublevel.
 - They can be in the same orbital.
 - They can have the same spin.



Ways to Describe Electrons in Atoms

- Arrows are added to an **orbital diagram** to show the distribution of electrons in the possible orbitals and the relative spin of each electron. The following is an orbital diagram for a nitrogen atom.



- The information in orbital diagrams is often described in a shorthand notation called an **electron configuration**.



Electron Configurations

- The sublevels are filled in such a way as to yield the lowest overall potential energy for the atom.
- No two electrons in an atom can be the same in all ways. This is one statement of the **Pauli Exclusion Principle**.
- When electrons are filling orbitals of the same energy, they prefer to enter empty orbitals first, and all electrons in half-filled orbitals have the same spin. This is called **Hund's Rule**.



Electron Configurations (cont.)

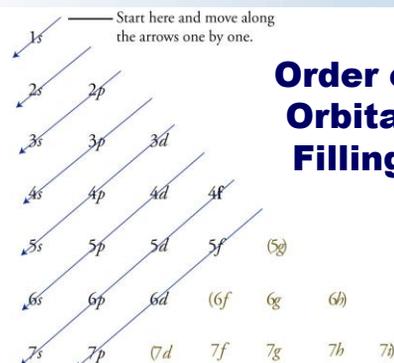
Represents the principal energy level

Shows the number of electrons in the orbital

1s²

Indicates the shape of the orbital

Order of Orbital Filling



1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p

Writing Electron Configurations

- Determine the number of electrons in the atom from its atomic number.
- Add electrons to the sublevels in the correct order of filling.
- Add two electrons to each *s* sublevel, 6 to each *p* sublevel, 10 to each *d* sublevel, and 14 to each *f* sublevel.
- To check your complete electron configuration, look to see whether the location of the last electron added corresponds to the element's position on the periodic table.



Order of Filling from the Periodic Table

Long Periodic Table

Drawing Orbital Diagrams

- Draw a line for each orbital of each sublevel mentioned in the complete electron configuration. Draw one line for each s sublevel, three lines for each p sublevel, five lines for each d sublevel, and seven lines for each f sublevel.
- Label each sublevel.
- For orbitals containing two electrons, draw one arrow up and one arrow down to indicate the electrons' opposite spin.
- For unfilled sublevels, follow Hund's Rule.

Abbreviated Electron Configurations

- The highest energy electrons are most important for chemical bonding.
- The noble gas configurations of electrons are especially stable and, therefore, not important for chemical bonding.
- We often describe electron configurations to reflect this representing the noble gas electrons with a noble gas symbol in brackets.
- For example, for sodium
 $1s^2 2s^2 2p^6 3s^1$ goes to $[\text{Ne}] 3s^1$

Writing Abbreviated Electron Configurations

- Find the symbol for the element on a periodic table.
- Write the symbol in brackets for the noble gas located at the far right of the preceding horizontal row on the table.
- Move back down a row (to the row containing the element you wish to describe) and to the far left. Following the elements in the row from left to right, write the outer-electron configuration associated with each column until you reach the element you are describing.

Abbreviated Electron Configurations – Optional Step

- Rewrite the abbreviated electron configuration, listing the sublevels in the order of increasing principal energy level (all of the 3's before the 4's, all of the 4's before the 5's, etc.)

Group 1 Abbreviated Electron Configurations

3
Li
[He] $2s^1$

11
Na
[Ne] $3s^1$

19
K
[Ar] $4s^1$

37
Rb
[Kr] $5s^1$

55
Cs
[Xe] $6s^1$

Abbreviated Electron Configuration Steps for Zinc

Step 1 Find the symbol for the element (zinc).

Step 2 Write the symbol in brackets for the nearest, smaller noble gas.

Step 3 Write the outer electron configuration for the remaining electrons.

$[Ar] 4s^2 3d^{10}$

1	2											18	8A				
1A	2A											18	8A				
3	4											2	He				
Li	Be											Ne					
11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Na	Mg	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
55	56	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
87	88	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uu	Uub	Uut	Uuq	Uur	Uus
		57	58	59	60	61	62	63	64	65	66	67	68	69	70		
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb		
		89	90	91	92	93	94	95	96	97	98	99	100	101	102		
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No		

Common Mistakes

- Complete electron configurations – miscounting electrons (Use the periodic table to determine order of filling.)
- Orbital diagrams – forgetting to leave electrons unpaired with the same spin when adding electrons to the p , d , or f sublevels (Hund's Rule)
- Abbreviated electron configurations
 - Forgetting to put $4f^{14}$ after [Xe]
 - Forgetting to list sublevels in the order of increasing principal energy level