CHAPTER 5
Electrons inAtoms

5.1 Light & Quantized Energy

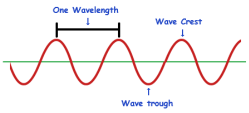
Was the Nuclear Atomic model incomplete?

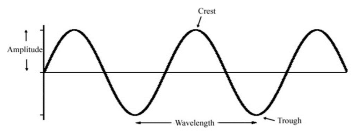
- To most scientists, the answer was yes.
- The arrangement of electrons was not determined
  - > *Remember...the arrangement of electrons is what determines the properties of atoms.*
- Rutherford's model did not explain electron arrangement or how it determined an atoms properties.

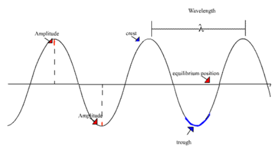
Wave Nature of Light

Electromagnetic Radiation:

- A form of energy that exhibits wavelike behavior as it travels through space.
- Visible light, x-rays,microwaves, radio waves



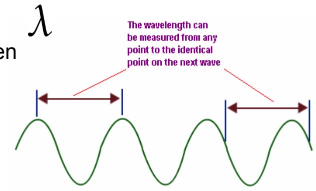




Parts of a Wave

Wavelength λ

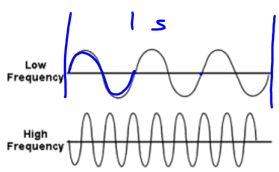
- shortest distance between equivalent points on a continuous wave
- measured from crest to crest or trough to trough



Parts of a Wave

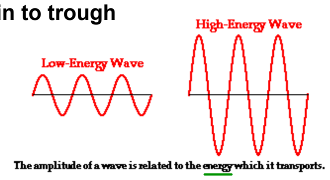
Frequency: ν

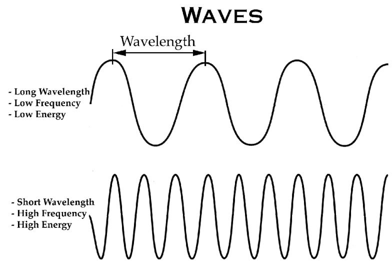
- the number of waves that pass a given point per second.
- One hertz (Hz) means 1 wave/second.
- 652 Hz = 652 waves/ second



Parts of a Wave

Amplitude: the wave's height from the origin to a crest or origin to trough





The Speed of Light

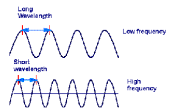
- All electromagnetic waves travel at the same speed in a vacuum. (3.00×10^8 m/s)
- A vacuum means there is not matter.
- The speed of all waves is the same, but their wavelengths and frequencies vary.
- Given the symbol "c"

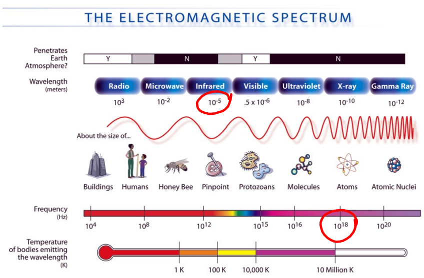
$\lambda\nu = c$ where:
λ is wavelength,
ν is frequency,
c is speed of light

Relating Frequency to Wavelength

Wavelength and frequency are inversely related.
As one increases, the other decreases.

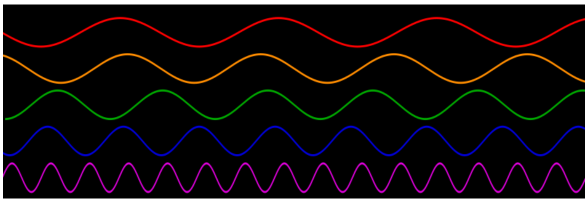
- ***Red Light = Long wavelength, low frequency***
- ***Violet Light = Short wavelength, high frequency***





What is the frequency of infrared waves?

What is the wavelength of an X-ray?



Electromagnetic Spectrum

All electromagnetic radiation.

The distinction between forms of electromagnetic radiation is the difference between frequency and wavelength of the waves.

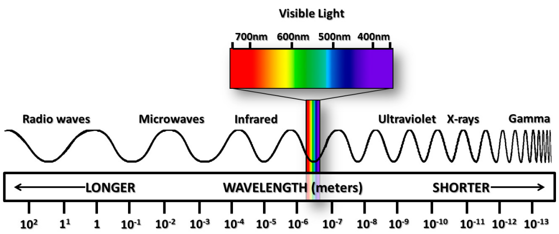
High frequency waves have more energy, but don't travel through matter as well.

Low frequency, Long wavelength waves have less energy but travel better through matter

Energy of Visible Light: ROYGBIV

High Energy: Violet
Low Energy: Red

***All colors of light travel the same speed!**



Calculating Wavelength of an EM Wave

Remember, all EM waves have the same speed.

$c = \lambda v$ Manipulate the formula to solve for the unknown.

What is the wavelength of a microwave with the frequency of 3.44×10^{9} Hz? (Hertz = 1/s)

$$\lambda = c/v = \frac{3.00 \times 10^{8}\ m/s}{3.44 \times 10^{9}\ 1/s} = 8.72 \times 10^{-2}\ m$$

Particle Nature of Light

The temperature of an object is the amount of kinetic energy its particles possess

Due to the varying energy, they particles emit different colors of light.

The different colors of light have different frequencies and wavelengths.

Blue light has a higher frequency than red light, hence, more energy.

The Quantum Concept

Max Planck studied energy changes in matter

- Matter can gain or lose energy in small, specific amounts called quanta.

Quantum: the minimum amount of energy that can be gained or lost by an atom.

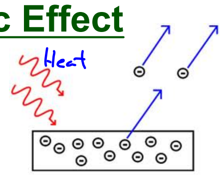
- Energy is gained or lost in steps, not gradually.

Planck's Constant: "*h*" 6.626×10^{-34} J·s

- For a given frequency, matter can emit or absorb energy only in whole number multiples
- If energy is a ladder, you can add a step or lose a step, however, you can not add a partial step.
- Matter can only have certain amounts of energy since partial steps of energy do NOT exist.

The Photoelectric Effect

When matter *(metals)* emits electrons upon absorption of electromagnetic energy, they are called photoelectrons



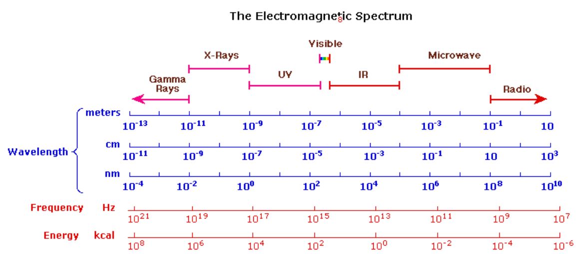
Photon: bundles of energy

- a particle of electromagnetic radiation that has no mass and carries a quantum of energy

Calculating the Energy of a Photon

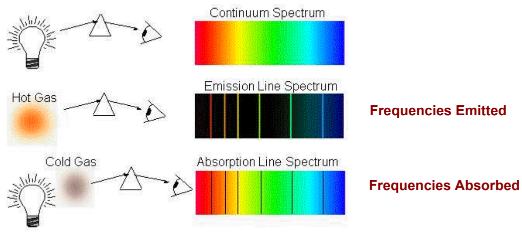
Violet light has a frequency of 7.23×10^{14} Hz. What is the energy of one photon of violet light?

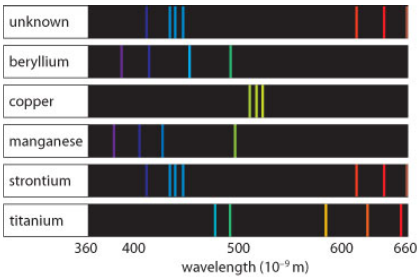
$E_{photon} = hv$ *(Planck's constant x frequency)*

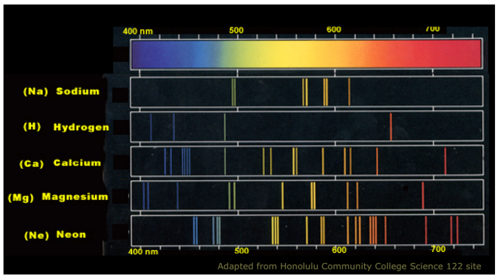


Atomic Emission Spectra

- The set of frequencies of the electromagnetic waves emitted by atoms of the element.
- Unique to each element.
- Can be used to identify elements.







Wave Model vs. Particle Model

The wave model explains that energy travels through space as an electromagnetic wave, but could not explain the color of light. wavelengths vs. Frequencies

The particle model explains how certain frequencies of light are emitted when objects are at a certain temperature. Energy is a photon.

Reviewing the 1st Atomic Models

The first model of the atom was Dalton's, who stated atoms were indivisible...

With the discovery of subatomic particles, this model was proven wrong.

Therefore, we needed new models that showed the arrangement of electrons.

Plum-Pudding Model

- Thomson
- Discovered electron
  - **"raisins" (electrons) in pudding (matter)**
- He did not mention the amount of electrons, ions, or the arrangement.

Rutherford Model

- Discovered nucleus
- Electrons surround a dense nucleus
- Rest of the atom empty space
- No mention of what was inside the nucleus

5.2 Quantum Theory & the Atom

The Chemical properties of atoms, ions, and molecules are related to the arrangement of the electrons within them.

Bohr Model

- Worked with Rutherford.
- Electrons arranged in circular orbits around a positively charged nucleus (1913)
- Patterned after the planets
- n = energy level
- $2n^2$=electrons in energy level (n)

Bohr & Energy States

- **The energy that atoms possess can change frequently.**
- **The smaller the orbit of the electron (energy level), then lower the energy.**
- **The larger the orbit of the electron (energy level), then higher the energy.**

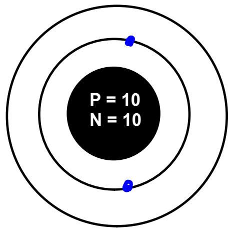
Bohr & Quantum Number

- **Each orbit was assigned a Quantum Number (*n*) to each orbit.**
- **Electrons are located in energy levels with a fixed amount of energy.**
- **The Energy levels farthest away from the nucleus are closer together.**

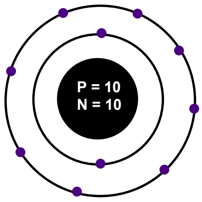
Electrons in Energy Levels

- 1st: $2(n)^2$ = $\mathbf{2(1)^2}$ = **2**
- 2nd: $2(n)^2$ = $\mathbf{2(2)^2}$ = **8**
- 3rd: $2(n)^2$ = $\mathbf{2(3)^2}$ = **18**
- 4th: $2(n)^2$ = $\mathbf{2(4)^2}$ = **32**

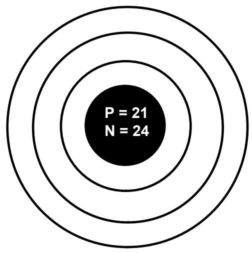
Bohr Model for Neon



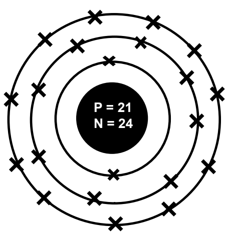
Bohr Model for Neon



Bohr Model for Scandium



Bohr Model for Scandium



Energy Levels

How many electrons fit in the 1st, 2nd, and 3rd, energy levels combined?

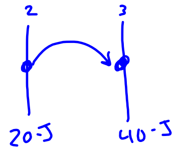
Energy Levels

- **High Energy levels** = High Energy
- **Low Energy levels** = Low Energy

- As electrons move from a lower to a higher energy level, they absorb a quantum of energy.

Quantum of energy

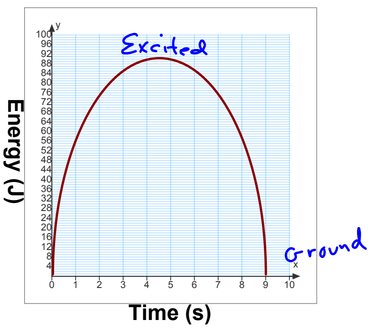
- **Amount of energy required to move an electron from one energy level to another**
- **Quantum Leap**



Energy Release or Absorption

Electrons move Away from nucleus = energy gain or absorption

Electrons move toward nucleus = energy loss or light released

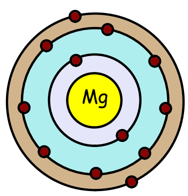


State of Electrons

Ground State: minimum amount of energy in electron (Low Energy level)

Excited State: energy has been gained by electron (High energy level)

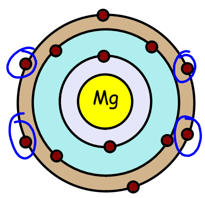
Ground State



Fixed Energy

- 1st: 10-joules
- 2nd: 40-joules
- 3rd: 60-joules

Excited State



Energy Levels are not equally spaced!

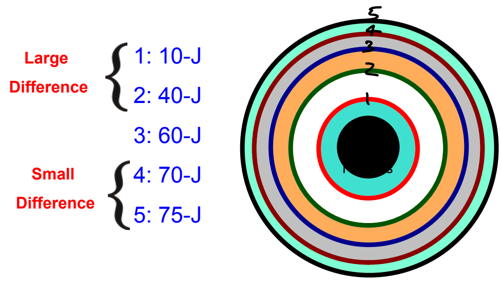
They become closer together as they move farther away from the nucleus.

Requires less energy to move as you reach higher levels.

Why is less energy required to move between energy levels as you move away from nucleus?

1. Energy levels become closer together as you move away from the nucleus

2. The energy differences between higher energy levels is much smaller than between lower energy levels.



Problems with Bohr's Model

- It explained Hydrogen's spectral lines but failed to explain the spectrum of any other element.
- Did not account for the chemical behavior of elements.
- Most evidence showed that electrons do not move in circular orbits.

THE QUANTUM MECHANICAL MODEL

- Louis de Brogile (1924)
- Scientists were convinced the Bohr model was incorrect.
- Proposed an idea that accounted for the fixed energy levels of Bohr's model.

Heisenberg Uncertainty Principle

- It is fundamentally impossible to know precisely both velocity and position of a particle at the same time.
- The act of observing an electron is actually changing it's position and it's motion.

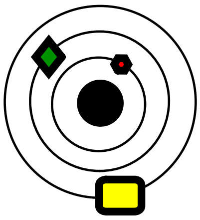
THE QUANTUM MECHANICAL MODEL

- Schrödinger (1926)
- Treated electrons as waves and applied to all elements, not just hydrogen.
- Does not describe the path around the nucleus
- Determines the probability of finding electrons in a particular space within an atom.

Atomic Orbital

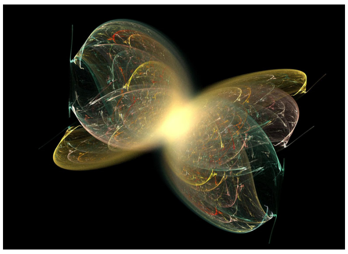
- The 3-dimensional space around the nucleus that describes the electrons probable location.
- Fuzzy cloud
- The more dense the cloud, the greater likelihood of finding an electron.
- Gives a 90% probability of finding an electron

THE QUANTUM MECHANICAL MODEL



Electrons are not spread througout an energy level, but they are in the cloud...

Electron Cloud



- n = energy level
- n = principal quantum number (1,2,3. . .) *(Outer energy level)*
- 4 types of sublevels. (s,p,d,f)
- The sublevels make up the clouds in the atom.

Principal Quantum Number (*n*)

Indicates the relative size and energies of atomic orbitals.

The outermost energy level indicates the size of the atom.

"n" specifies the atom' major energy levels, called the principal energy levels.

Energy Sublevels

Sublevels make up energy levels.

As you move away from the nucleus, energy levels get larger and contain more sublevels.

Sublevels are labeled s, p, d, or f according to the shapes of the orbitals within them.

Energy Levels→sublevels → orbitals

Energy Sublevels

- n = 1: 1 sublevel (s)
- n = 2: 2 sublevels (s & p)
- n = 3: 3 sublevels (s, p, & d)
- n = 4: 4 sublevels (s, p, d, & f)

Orbitals make up sublevels

4 types of sublevels

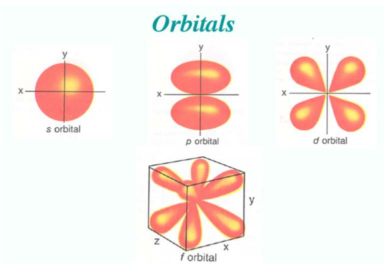
Sublevels describe the shapes of the orbitals.

Different sublevels have different shaped orbitals

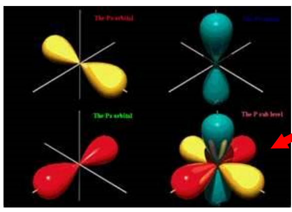
Each orbital can hold 2 electrons.

ATOMIC ORBITALS

- The orbitals in each sublevel have a different shape.
- S = **sphere** (1 orbital)
- P =**dumbbell**(3 orbitals)
- D = **clover leaf** (5 orbitals)
- F = **not determined** (7 orbitals)

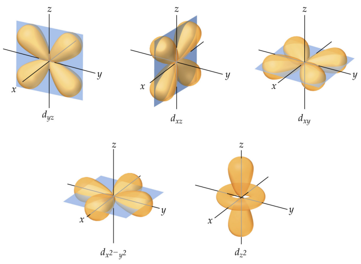


p orbitals



Notice how all 3 "*p*" orbitals fit together

***d* orbitals**



- S sublevel = 1 orbital
- p sublevel = 3 orbitals
- d sublevel = 5 orbitals
- f sublevel = 7 orbitals

Each orbital can be filled (2), half-filled (1), or empty (0).

- S sublevel = 2 electrons
- p sublevel = 6 electrons
- d sublevel = 10 electrons
- f sublevel = 14 electrons

***Each sublevel holds the same number* of electrons, regardless of the energy level.**

Energy Level	Electrons	Sublevels	Orbitals
1			
2			
3			
4			

1st: s
2nd: s + p
3rd: s + p + d
4th: s + p + d + f

1s			
2s	2 p		
3s	3p	3d	
4s	4p	4d	4f

Differentiating between the 5 Atomic Models

Dalton: atoms were indivisible
Plum Pudding: thomson said electrons float in matter
Rutherford: nuclear model
Bohr: determined there were energy levels
QMM: Schrodinger determined there were orbitals

Quiz 5.1 & 5.2

Differentiate between the 5 atomic models.
What are the shapes of 4 types orbitals?
How many electrons fit in each energy level?
Which sublevels are in each energy level?
How many orbitals are in each sublevel?
How many sublevels are in each energy level?
How many orbitals are in each energy level?
How many electrons fit in each sublevel?
Find the wavelength given frequency.
Find the frequency given wavelength.
Find the E_{photon} given the frequency.
Find the E_{photon} given the wavelength.

Test Questions

Which of the following has 5 orbitals?

a.) 2p b.) 2d c.) 4f d.) 3d e.) b & d

Which energy level can only hold 4 orbitals?

a.) 1st b.) 2nd c.) 3rd d.) 4th

5.3 Electron Configurations

The way in which electrons are arranged around the nuclei of atoms.

Ground state electron configurations show the most stable, lowest-energy arrangement of the elctrons in the atoms of each elements.

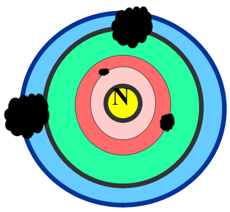
Aufbau Principle

- Electrons enter orbitals *(not energy levels)* of lowest energy first

- Aufbau Chart
- Diagonal Diagram

some 4th energy level orbitals fill before 3rd energy level orbitals

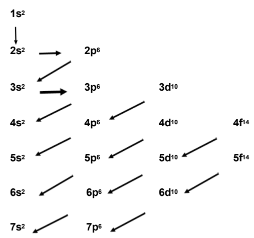
Overlapping of Electrons



As you can see, the cloud for the 3rd energy level overlaps the 4th energy level.

The Cloud in the 4th energy level overlaps the 3rd energy level.

Diagonal Diagram (Aufbau Chart)



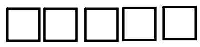
Pauli Exclusion Principle

- An atomic orbital can only hold two electrons
- If there are two, they must have opposite spins.
- Clockwise or counterclockwise

Hund's Rule

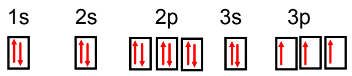
When electrons occupy orbitals of equal energy, one electron enters each orbital until all orbitals contain one electron with spins parallel.

5d orbitals with equal energy



Orbital Diagram for Phosphorus

P:

P: 

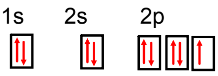
Electron Configuration for Phosphorus

P:

P: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$

Orbital Diagram for Fluorine

F:

F: 

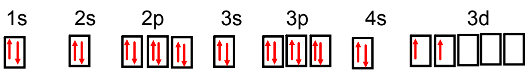
Electron Configuration for Fluorine

F:

F: $1s^2\ 2s^2\ 2p^5$

Orbital Diagram for Titanium

Ti:

Ti: 

Electron Configuration for Titanium

Ti:

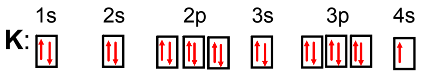
Ti: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^2$

Important Questions using a Potassium Atom

1. Highest full Energy level?
2. Highest full sublevel?
3. Highest occupied Energy level?
4. Number of unpaired electrons?
5. Number of empty orbitals?

Orbital Diagram for Potassium

K:



Electron Configuration for Potassium

K:

K: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$

Important Questions using a Molybdenum Atom

1. Highest full Energy level?
2. Highest full sublevel?
3. Highest occupied Energy level?
4. Number of unpaired electrons?
5. Number of empty orbitals?

Electron Configuration for Molybdenum

Mo: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^4$

Orbital Diagram for Molybdenum

1. Which atom is the first to have a "p" electron?

- $1s^2\ 2s^2\ 2p^1$

2. What atom has the following configuration?

- $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

3. What atom has 7 electrons in the 3d sublevel?

- $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^7$

Abbreviated Electron Configurations

(Noble Gas Notation)

- [Ne] = $1s^2 2s^2 2p^6$
- [Ar] = $1s^2\ 2s^2\ 2p^6\ 3s^2 3p^6$
- [Kr]= [Ar] $4s^2 3d^{10} 4p^6$
- Cl: [Ne] $3s^2 3p^5$
- Ca: [Ar] $4s^2$

Steps for Abbreviated Configurations

1. Locate the noble gas in the previous period.
2. Subtract the number of electrons in the noble gas from the electrons in your element.
3. Find the last sublevel of the noble gas.

Abbreviated Electron Configurations

Carbon:

- C: [He] $2s^2$ 2p2

Nickel:

- Ni: [Ar] $4s^2$ $3d^8$

Abbreviated Electron Configurations

Sulfur:

- S: [Ne] $3s^2$ $3p^4$

Molybdenum:

- Mo: [Kr] $5s^2$ $4d^4$

Ground State of Atoms

Electrons fill up orbitals, sublevels, and energy levels according to the diagonal diagram and your rules.

- The basic electron configuration.
- No energy!

Excited State of Atoms

- Electrons jump from one energy level to the next and the they become excited.
- Incorrect electron configuration.
- Higher energy.

1) enough energy
2) room to jump

$1s^2 2s^2 2p^6 3s^2 3p^1$

Ground State of Chromium

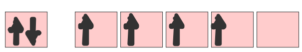
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^4$

Excite State of Chromium

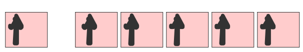
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$

Which version of Chromium is more stable?

[Ar] $4s^2$ $3d^4$



[Ar] $4s^1$ $3d^5$



EXCEPTIONAL ELECTRON CONFIGURATIONS

- **Up to atomic number 23 there are NO exceptions**
- **After that exceptions may occur, meaning they don't follow diagonal diagram.**

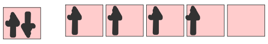
Partially filled orbitals are much more stable than empty orbitals!!!!

This is how we get exceptions!

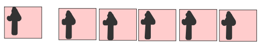
The electrons in full orbitals will sometimes move to empty orbitals to make the atom more stable.

Which version of Molybdenum is more stable?

[Kr] 5*s* 2 4*d* 4

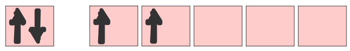


[Kr] 5*s* 1 4*d* 5



Would Zirconium be an exception?

[Kr] 5*s* ^{2} 4*d* ^{2}



Valence Electrons

The electrons in an atom's outermost "s" and "p" orbitals.

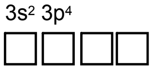
Sulfur: [Ne] $3s^2$ $3p^4$ (6 valence electrons)

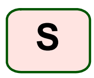
Calcium: [Ar] $4s^2$ (2 valence electrons)

Electron Dot Structures

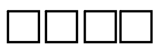
The s and p orbitals always have 4 orbitals, which means there are 4 sides to a dot structure.

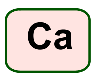
Sulfur: [Ne] $3s^2$ $3p^4$





Calcium: [Ar] $4s^2$





Chapter 5 Test

10 Matching: (Models, Laws, Vocabulary)
40 Multiple Choice:
-

Abbreviated is acceptable

You can use your periodic table!

Example Questions

How many empty orbitals in carbon?
What element has 6 electrons in the 3d sublevel?
What is the maximum number of orbitals in the f sublevel?
What determines the properties of an atom?
What types of sublevels can be present in the 3rd energy level?
How many electrons are in the outermost energy level of aluminum?
How many unpaired electrons are in nitrogen?
What is significant about the spacing of energy levels?