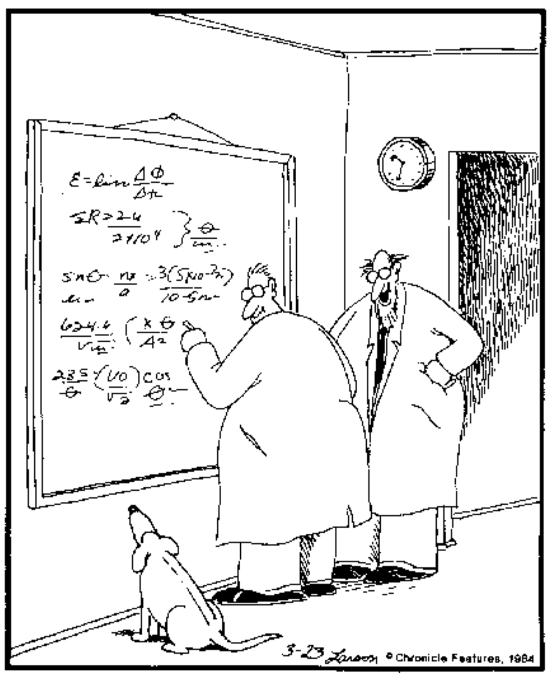
CHEMISTRY 40S

The Alchemist's Notebook

UNIT 5 – ATOMIC STRUCTURE



"Ohhhhhhh . . . Look at that, Schuster . . . Dogs are so cute when they try to comprehend quantum mechanics."

NAME:____________________________________

LET'S GET STARTED!

By the end of this unit, you should be able to:

- ✓ Describe qualitatively and quantitatively, the electromagnetic spectrum of radiation in terms of frequency, wavelength, and energy.
- ✓ Recognize, through direct observation, that elements have unique line spectra.
- ✓ Outline the historical development of the quantum mechanical model of the atom.
- ✓ Write electron configurations for elements of the periodic table.
- ✓ Relate the electron configuration of an element to its valence electron(s) and its position on the periodic table.
- ✓ Identify and account for periodic trends among the properties of elements and relate the properties to electron configuration

This unit will take approximately 10 lessons to complete and will comprise 10% of your mark in this class.

1. THE NATURE OF LIGHT

UNIT 5 – ATOMIC STRUCTURE

CH40S MR. WIEBE

INTRODUCTION

- Atomic structure explains chemical properties and patterns of chemical reactivity.
- Chemical reactions involve electrons. Knowing where the electrons are and how many there are helps explain many chemical phenomena.
- We use different forms of light to explore atomic structure (spectroscopy). Because of this, we start with a discussion of the nature of light.

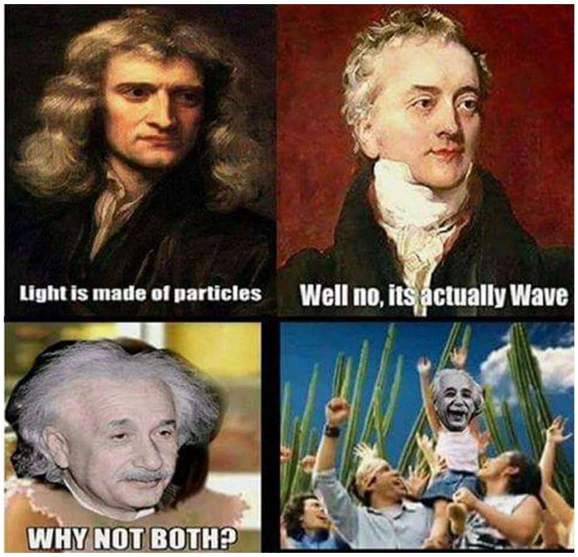
THE NATURE OF LIGHT - PARTICLES OR WAVES??

Isaac Newton: Light must be made of particles because it…

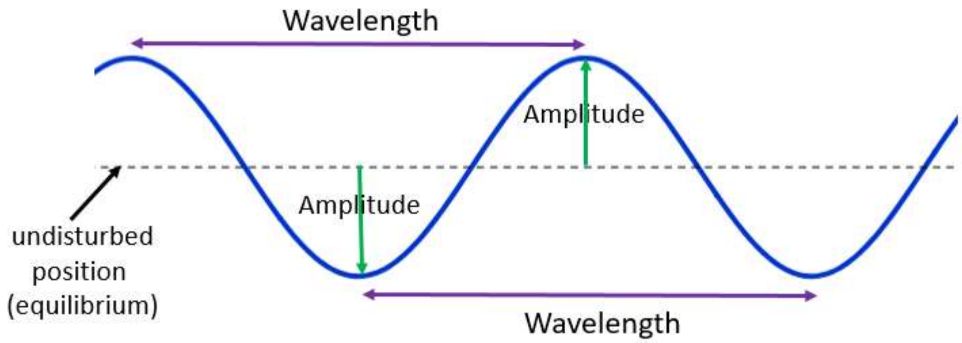
- travels in a vacuum
- reflects off objects
- exerts force (on the tails of comets)

Christiaan Huygens: Light must consist of waves because it…

- reflects like waves
- refracts and diffracts
- exhibits interference



GENERAL CHARACTERISTICS OF WAVES



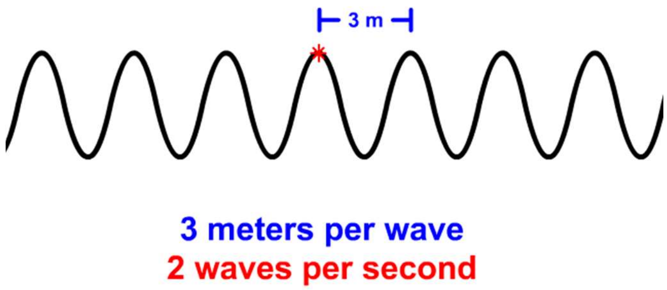
Amplitude: maximum displacement of a point on a wave away from its undisturbed position

Wavelength: distance from a point on one wave to the equivalent point on the adjacent wave.

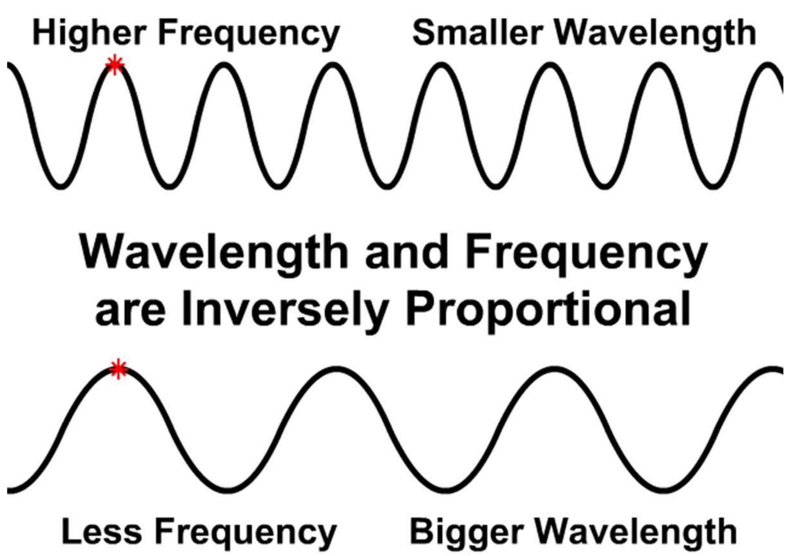
GENERAL CHARACTERISTICS OF WAVES

Frequency: the number of times a crest passes a fixed point per unit of time.

$$v = (\lambda)(f)$$



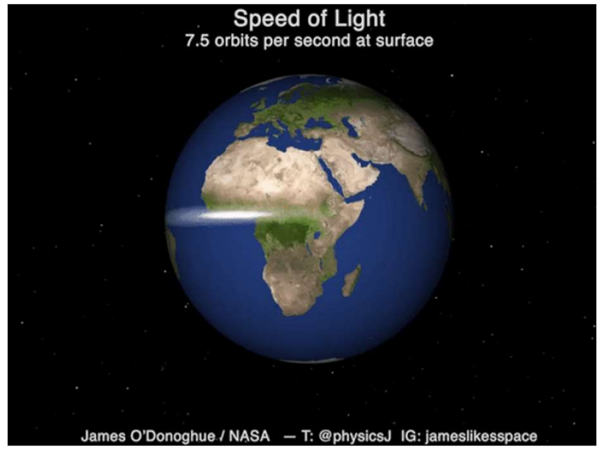
WAVELENGTH AND FREQUENCY



THE WAVE NATURE OF LIGHT

Light travels through space as a wave.

It travels at a constant speed equal to 3.00 x 10^8 m/s or 300 million m/s.



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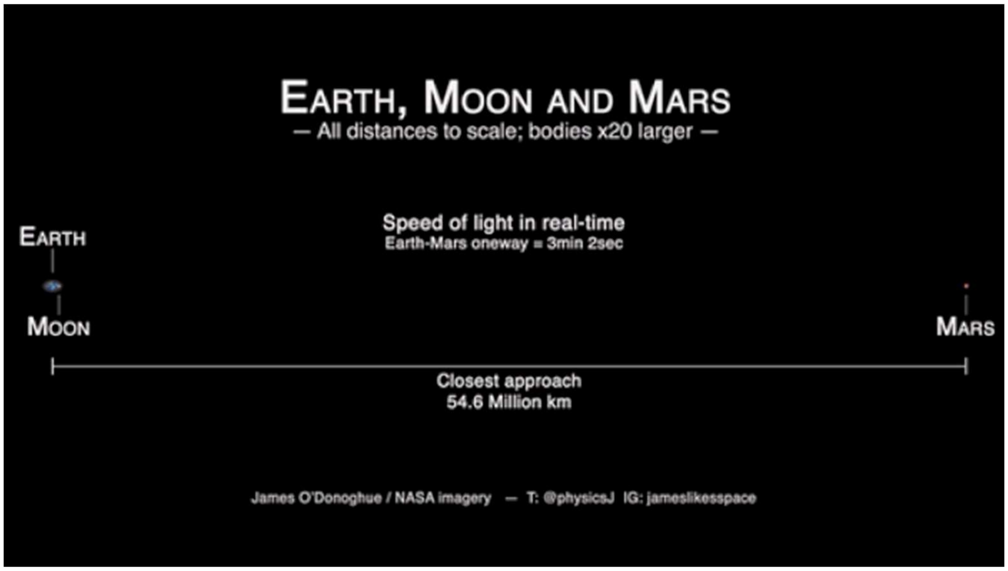
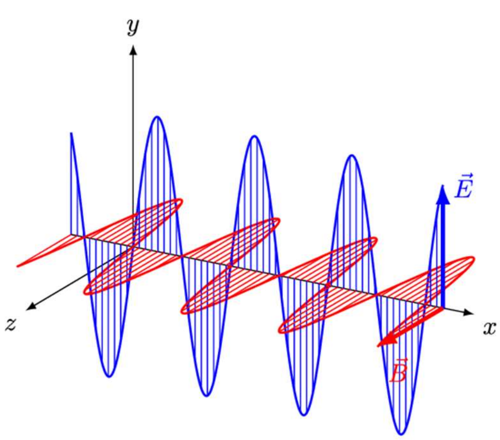
THE SPEED OF LIGHT IS FAST…

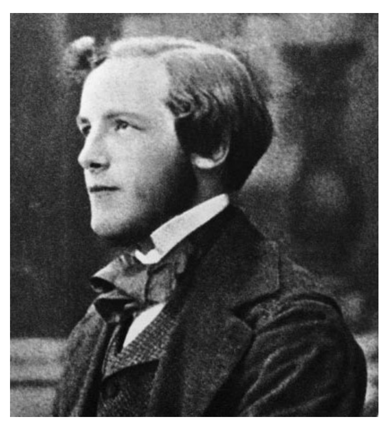
…BUT ONLY RELATIVELY.



BY THE END OF THE 1800's…

Light is an electromagnetic wave composed of continuous wavelengths that form a spectrum. Light and matter are two distinctly different entities.

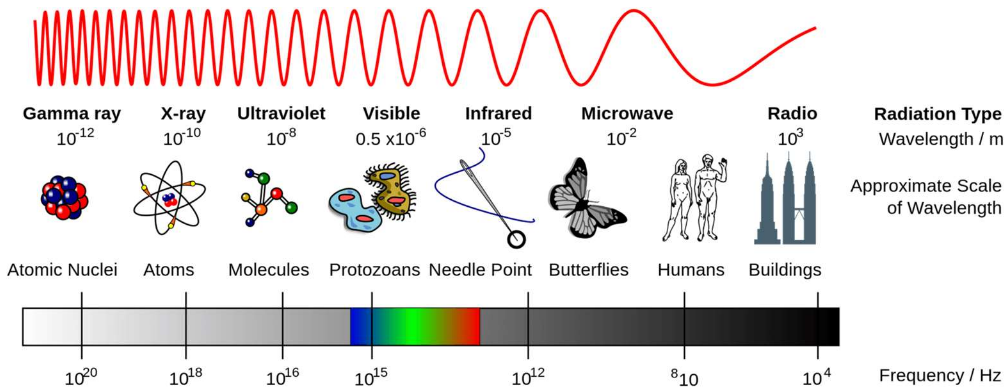




JAMES MAXWELL

ELECTROMAGNETIC RADIATION (EMR)

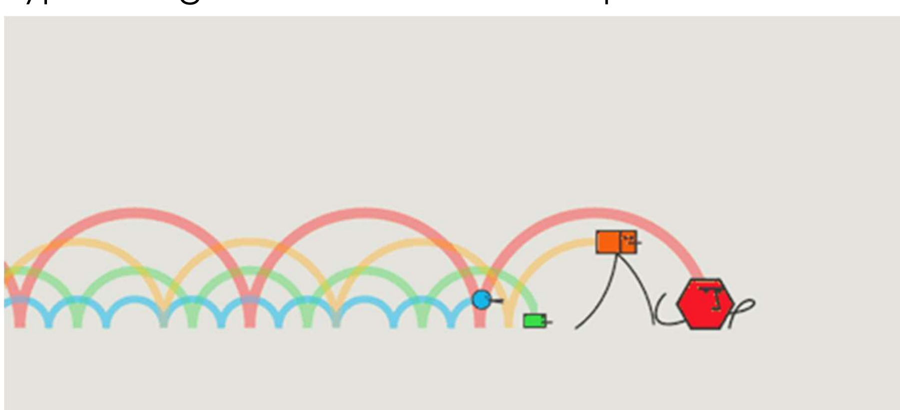
Light can be broken down into 7 different types. These types are categorized based on wavelength and frequency.



Raging Martians Invaded ROY G. BIV Using X-Ray Guns

SUMMARY

All types of light travel at the same speed.



Different types of light have different wavelengths and frequencies that are inversely proportional.

INFRARED SPECTROSCOPY

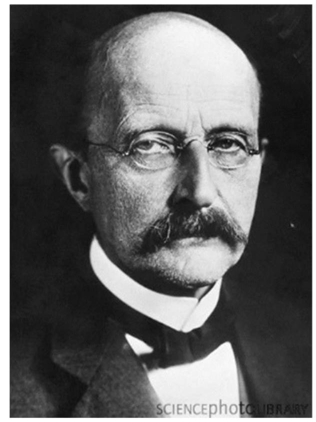
NASA's Hubble Space Telescope has cameras that can capture different wavelengths of light, resulting in images that show different perspectives of the same object.

THERMAL IMAGING

Thermal (infrared) imaging is very useful. It can be used to detect abnormal heat signatures in electrical circuits as well as in animals.

PARTICLE THEORY OF LIGHT

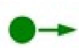
- In the early 1900's, new evidence was discovered by Max Planck, Albert Einstein, and others that resurrected the particle theory of light.
- Light is now thought to be composed of particles (quanta) each carrying a fixed amount of energy. These particles are called photons.
- The amount of energy per photon is directly proportional to the frequency of the light:

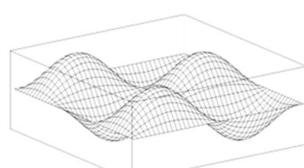


$$E = h\nu \quad \text{or} \quad E = \frac{hc}{\lambda} \quad , h = 6.626 \times 10^{-34}\ J \cdot s$$

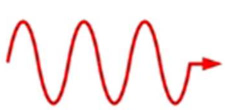
PHOTONS = WAVICLES?

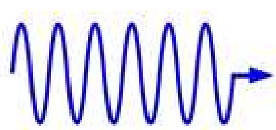
Particle + Wave =





PHOTONS!

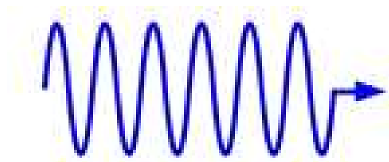




IN OTHER WORDS…

LARGE Wavelength = SMALL Frequency = SMALL ENERGY PHOTON

SMALL Wavelength = LARGE Frequency = LARGE ENERGY PHOTON



CONVERTING BETWEEN WAVELENGTH & FREQUENCY

$$c = \lambda v$$

λ = wavelength in **meters**

v = frequency ($\frac{1}{s}$ **becomes s^{-1} or Hz**)

c = speed of light (**3.00×10^8 m/s**)

ENERGY OF A PHOTON

$$E = h\nu \quad \text{or} \quad E = \frac{hc}{\lambda} \quad , h = 6.626 \times 10^{-34}\ J \cdot s$$

E = energy of photon (**J**oules)

h = Planck's Constant

V = frequency of wave (Hz or s^{-1})

DON'T FORGET SI UNITS!

Multiplication Factor	Prefix	Symbol
1,000,000,000 = 10^9	giga	G
1,000,000 = 10^6	mega	M
1,000 = 10^3	kilo	k
100 = 10^2	hecto	h
1 = 1		
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000001 = 10^{-6}	micro	µ
0.00000001 = 10^{-9}	nano	n

Gigantic Megaphones Killed 1 Million Microscopic Nanobots

CALCULATIONS INVOLVING EMR

The wavelength of maximum visual acuity in humans is 550 nm. (green light)

What is the frequency of a **single** photon having this wavelength?

Multiplication Factor	Prefix	Symbol
1,000,000,000 = 10^{9}	giga	G
1,000,000 = 10^{6}	mega	M
1,000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
1 = 1		
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000001 = 10^{-6}	micro	µ
0.00000001 = 10^{-9}	nano	n

CALCULATIONS INVOLVING EMR

The wavelength of maximum visual acuity in humans is 550 nm. (green light)

What is the energy of a **single** green photon having this wavelength?

What is the energy of a **mole** of green photons?

2. LINE SPECTRA OF ELEMENTS

UNIT 5 - ATOMIC STRUCTURE

CH40S MR. WIEBE

1

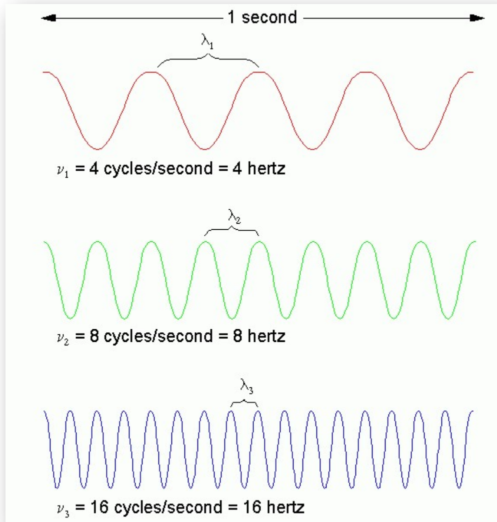
RECAP…

- Light (EMR) can be categorized by wavelength and frequency into a spectrum.
- Max Planck noticed that when matter absorbs waves of EMR (ie. Heating up a metal object), it doesn't do so in a continuous fashion. It does so in "chunks" or quanta called photons.
- The energy contained by each photon is directly proportional to the frequency of the EMR.

2

RELATIONSHIP BETWEEN VARIABLES

Long
Wavelength
=
Low Frequency
=
Low ENERGY



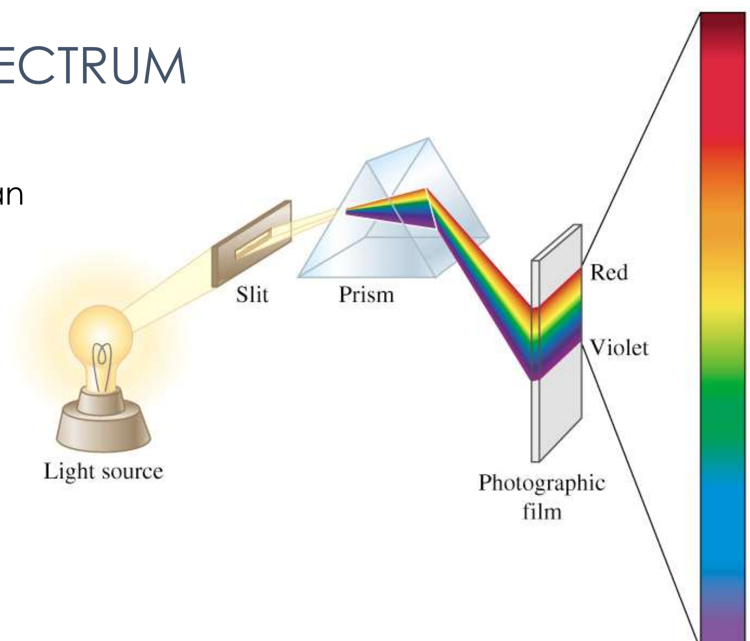
Short
Wavelength
=
High Frequency
=
High ENERGY

3

CONTINUOUS SPECTRUM

When white light (such as light from the sun or from an incandescent light bulb) is passed through a prism, it produces a <u>continuous spectrum</u> of colours.

White light is comprised of photons of every wavelength in the visible spectrum.



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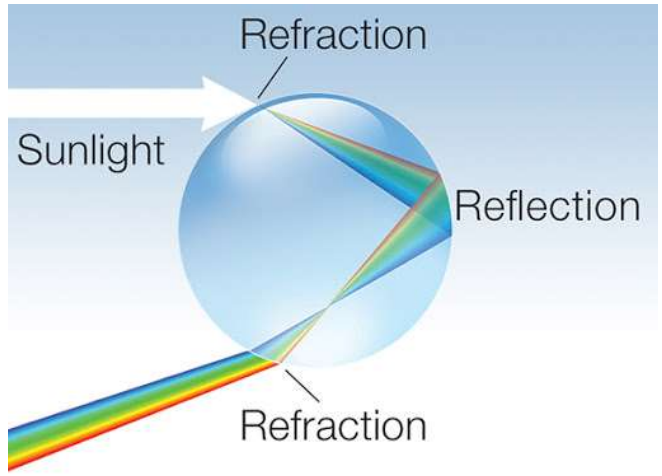
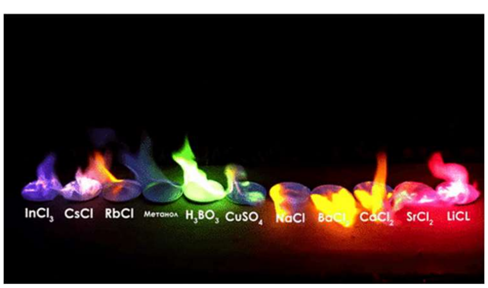
CONTINUOUS SPECTRUM

Rainbows are formed when raindrops act as prisms, separating the sunlight into all its component wavelengths to produce a continuous spectrum of photons.



FLAME COLOURS

When heat or electrical current are applied to samples of elements, different colours of light are produced.

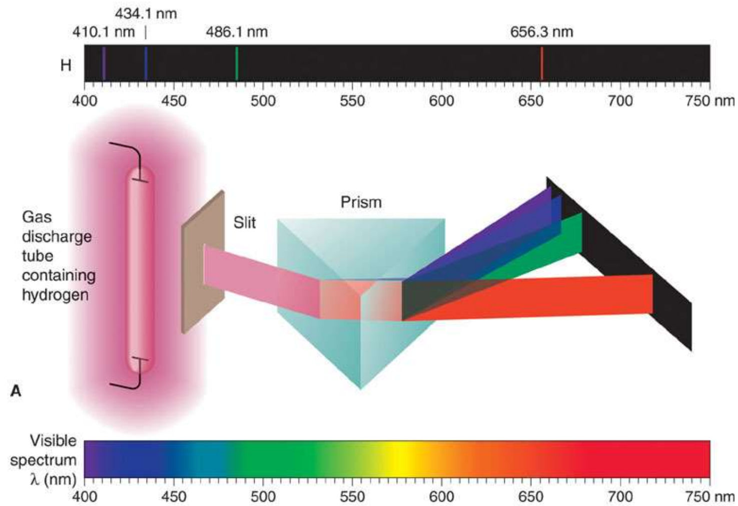


Every element produces a distinctly unique colour.

ATOMIC LINE SPECTRA

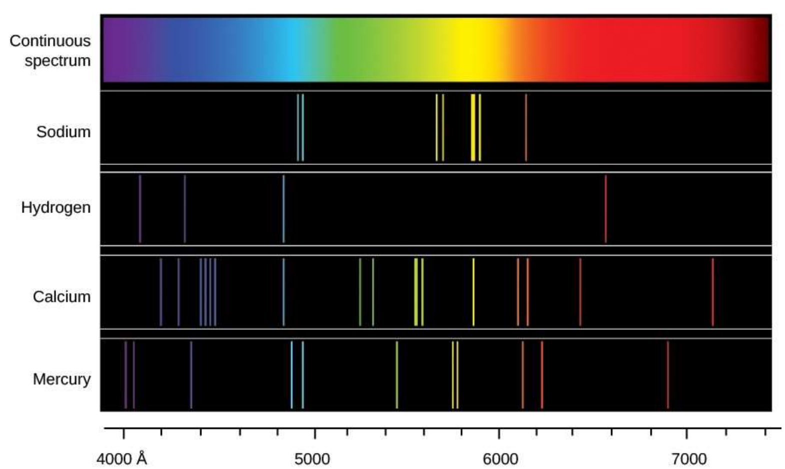
When this light is passed though a prism, a line spectrum is produced rather than a continuous spectrum.

For example, when hydrogen atoms are excited and the light produced is passed through a prism, only 4 wavelengths of light are produced.

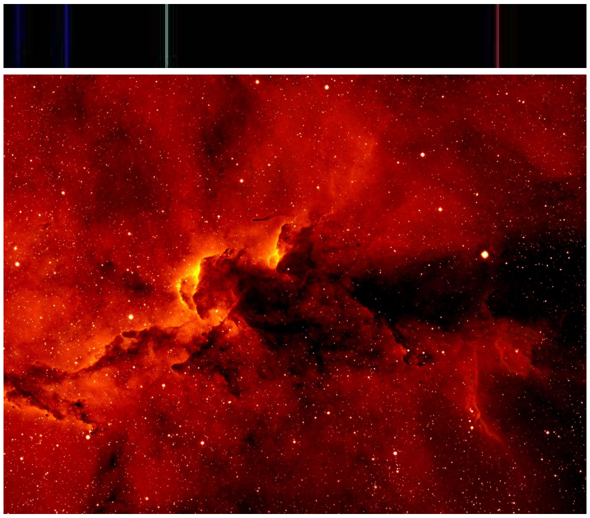


EMMISSION LINE SPECTRA

Every element has a unique line spectrum that can be used to identify them, like finger-prints.



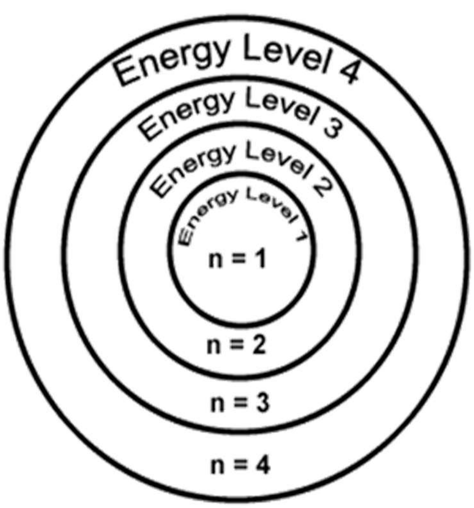
EMMISION LINE SPECTRA



When light from space is collected and passed though a prism, much of the time the line spectra match the line spectrum of hydrogen.

This is how we know 99.9% of our known universe is comprised of hydrogen.

WHY DOES THIS HAPPEN?



Remember that electrons are found in energy levels around the nucleus of atoms.

The farther away from the nucleus the electron (the higher the energy level), the more energy the electron must have to stay there.

Slide 10

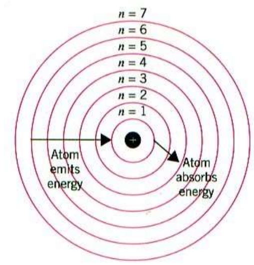
WHY DOES THIS HAPPEN?

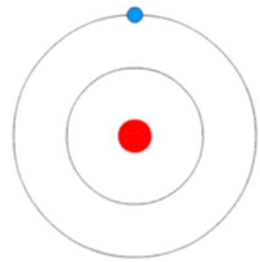
When an atom of hydrogen absorbs energy, the electron also increases in energy.

As a result, the electron gets promoted to a higher energy level. The atom is now in an excited state.

When the electron loses that energy, it returns to its natural energy level (ground state).

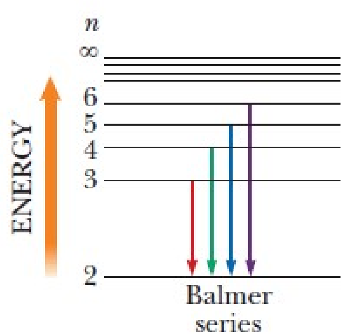
The energy lost as the electron falls is given off as a photon of light of equivalent energy.

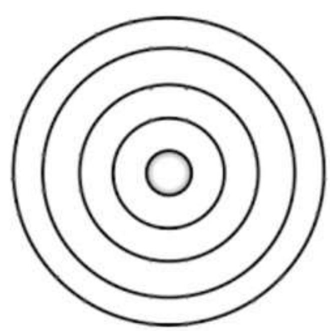




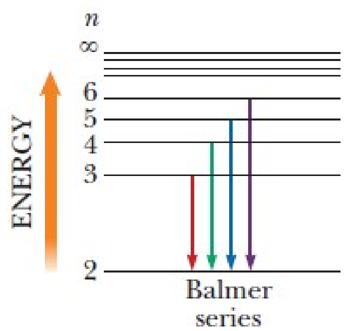
The time it takes for an electron to rise and fall is measured in zeptoseconds (10^{-21})!

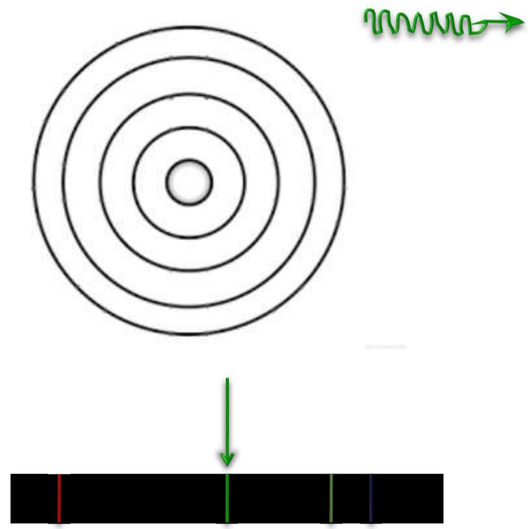
THE BALMER SERIES



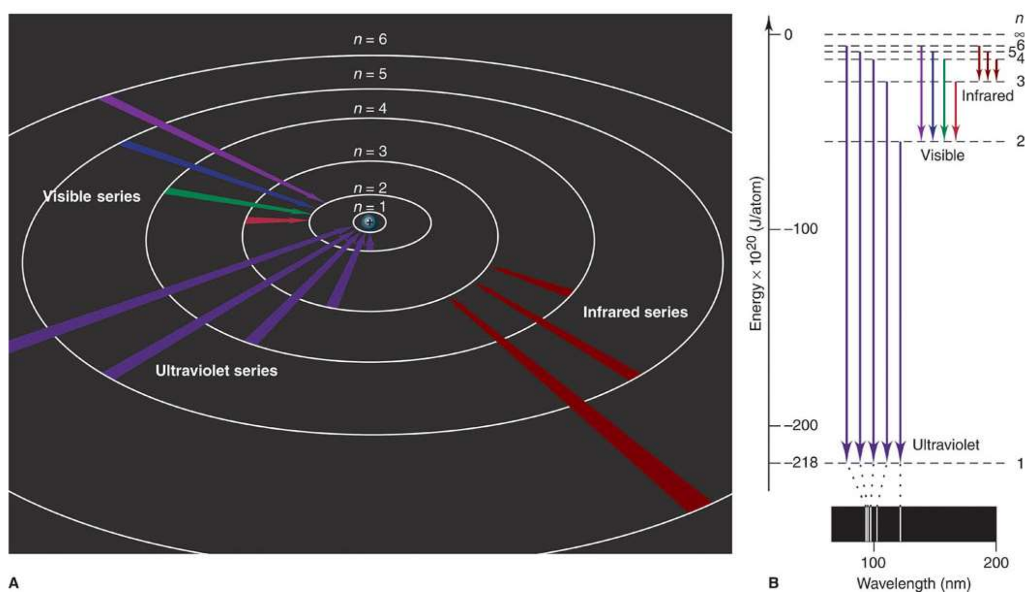


THE BALMER SERIES





THE BOHR MODEL REVISED

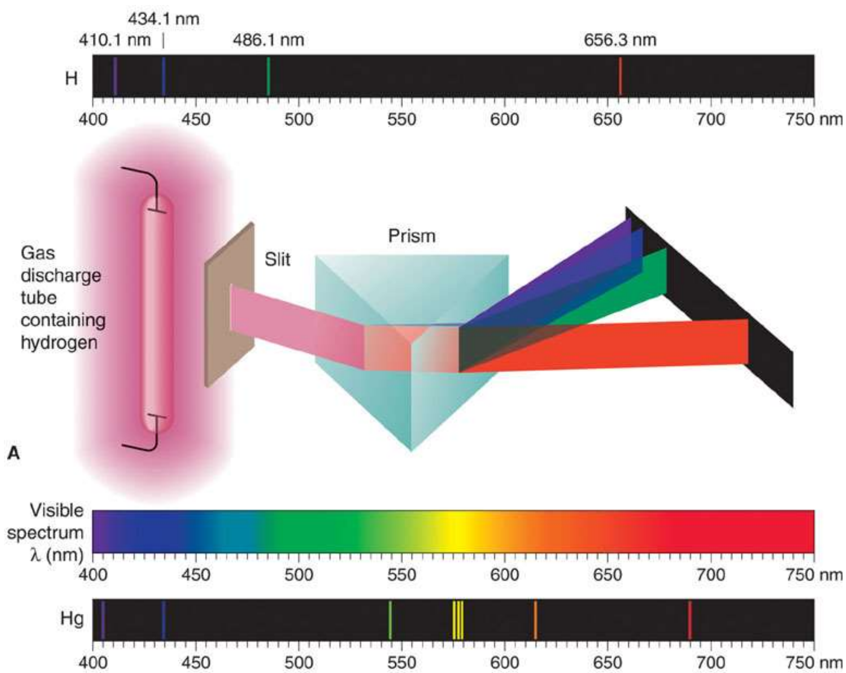


3. ELECTRON CONFIGURATIONS

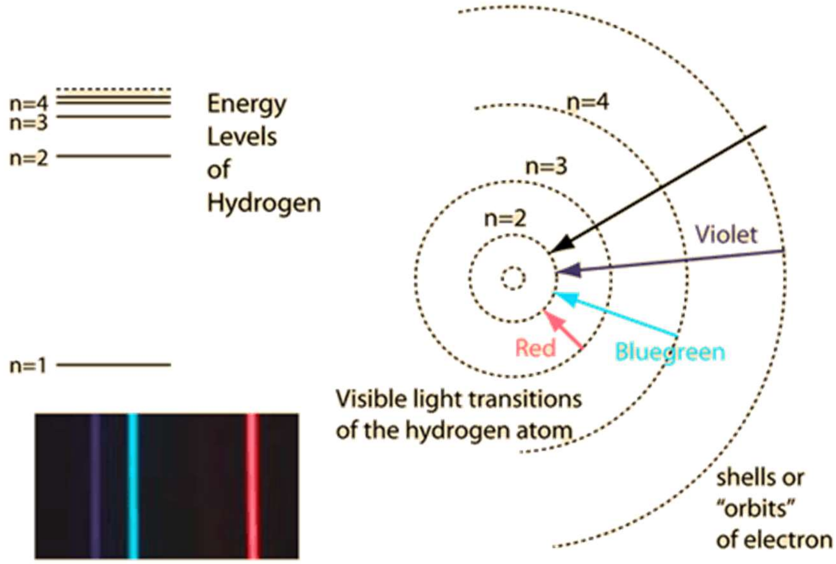
UNIT 5 – QUANTUM MODEL OF THE ATOM

CH40S MR. WIEBE

REVIEW



REVIEW



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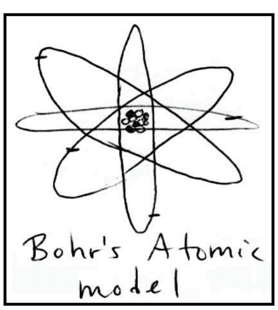
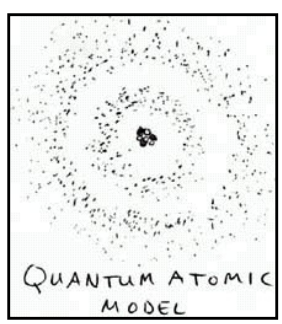
IS IT REALLY THAT SIMPLE?

- Although it works great for single-electron atoms, Bohr's model fails for atoms with 2 or more electrons!
- Ultimately, the failures of Bohr's model lay in the fact that he treated the electron as a particle rather than a wave!





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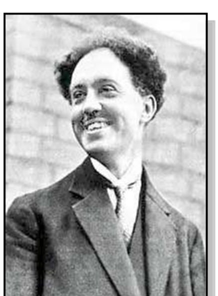
4

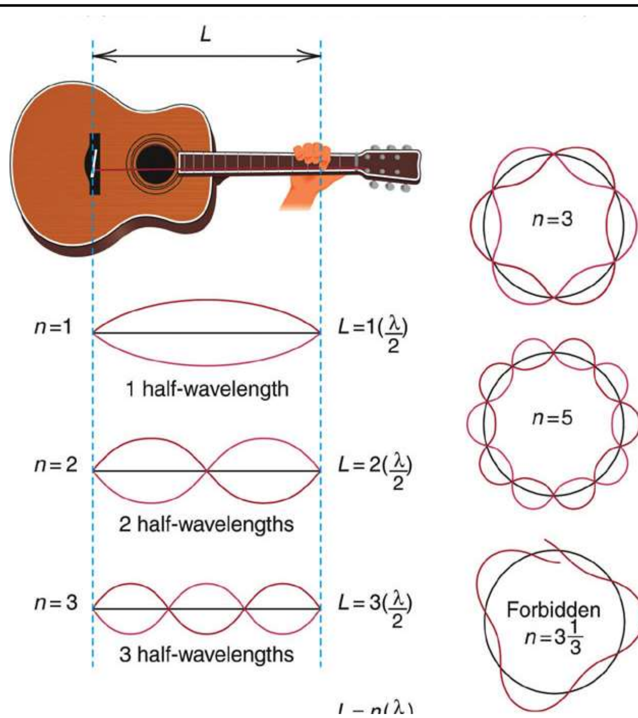
MODIFYING THE BOHR MODEL

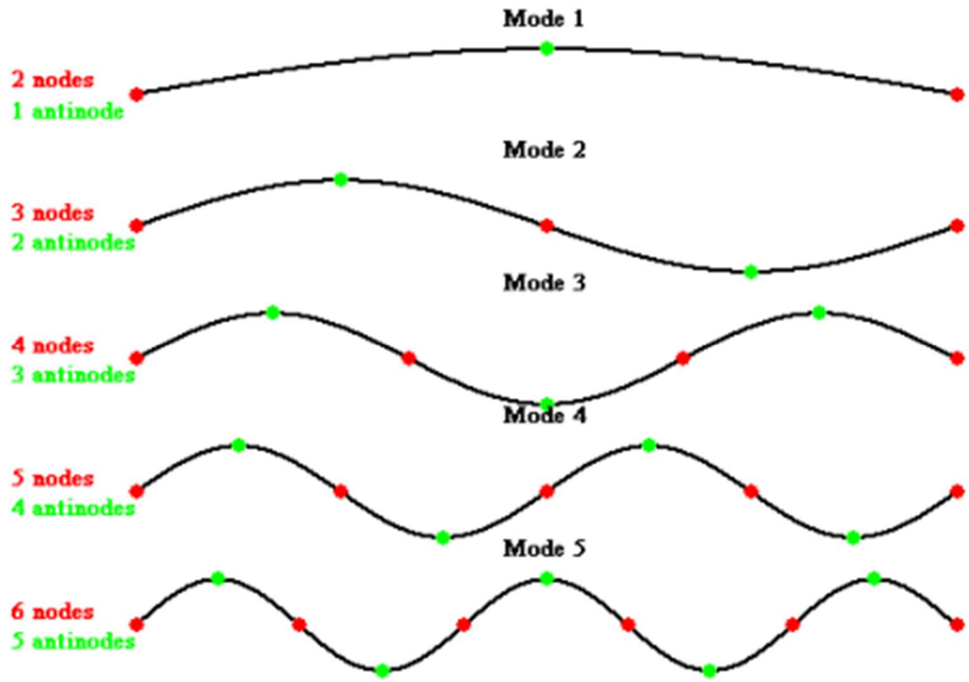
- Louis de Broglie made the leap that if light can behave as "wave-particles" or photons, then so can matter!
- He showed that the wavelength of a baseball is negligible (as expected), but that the wavelength of an electron was on the order of magnitude equal to that of electromagnetic radiation!
- This is what Bohr had missed – an atomic model must make use of the wave-nature of electrons to be complete!

Slide 5

Electrons Must Act Like Standing Waves







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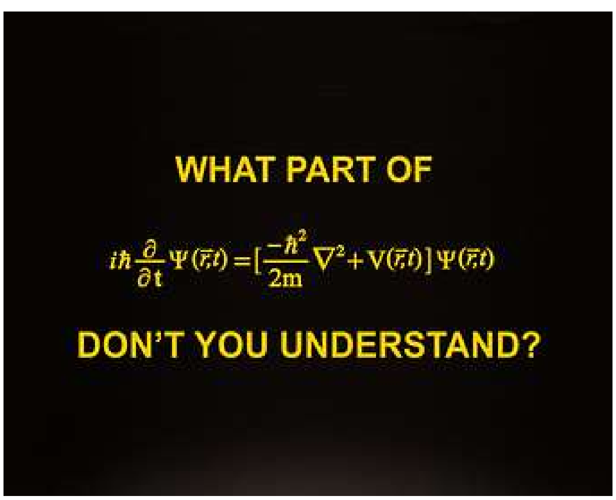
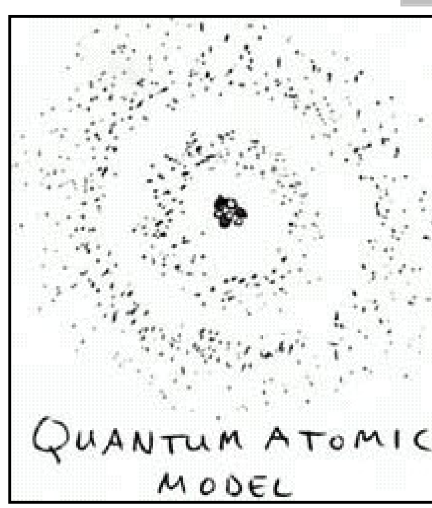
The Schrödinger Wave Equation





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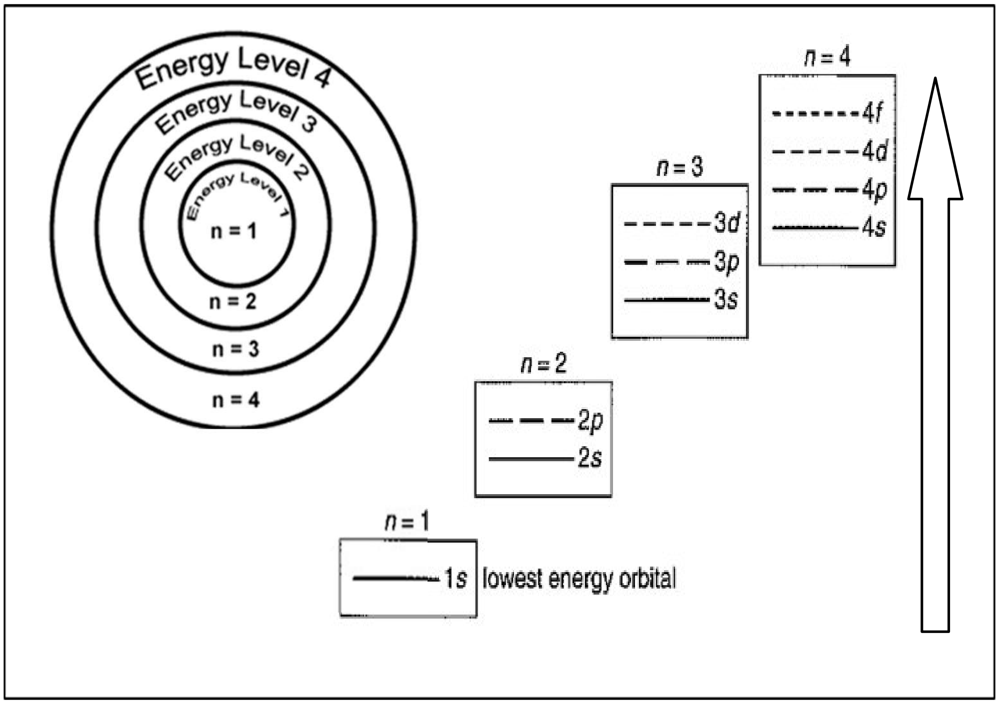
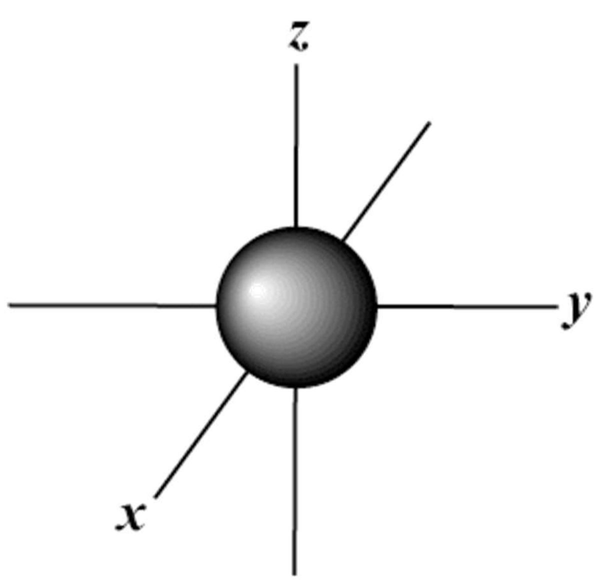


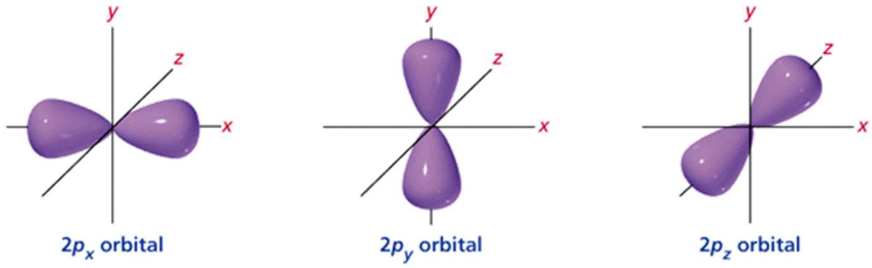
s orbitals

There is only 1 arrangement of an s orbital.

One s orbital is found in **<u>every</u>** energy level.



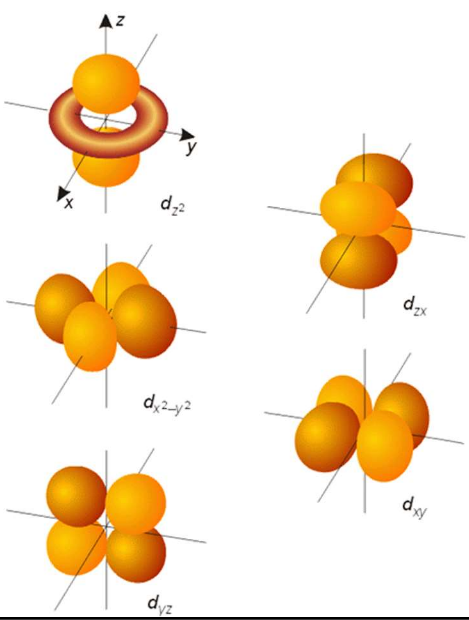
p orbitals



There are **3 arrangements** of p orbitals.

Three p orbitals are found in energy levels **after and including n=2**.

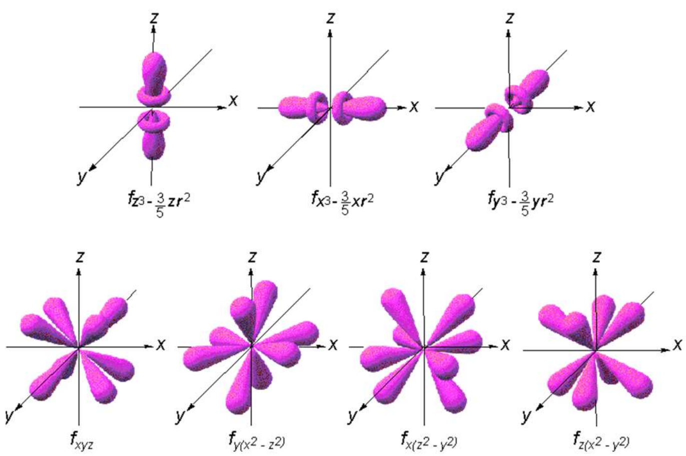
d orbitals



There are **5 arrangements** of d orbitals

Five d orbitals are found in energy levels **after and including n=3**.

f orbitals



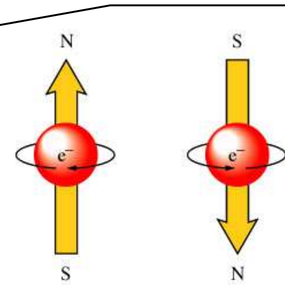
There are **7 arrangements** of f orbitals

Seven f orbitals are found in energy levels **after and including n=4**.

THE PAULI EXCLUSION PRINCIPLE

WOLFGANG PAULI

Electrons occupying the same orbital must have opposite spins. As such, the maximum number of electrons allowed in any orbital is 2!



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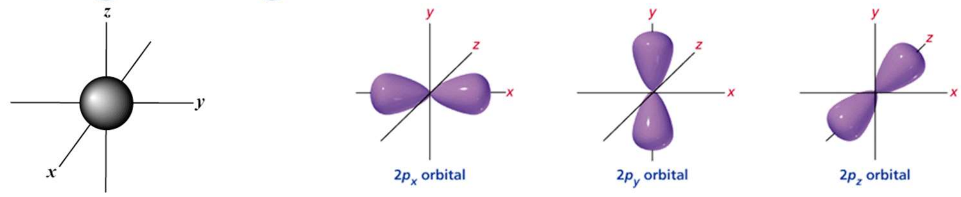
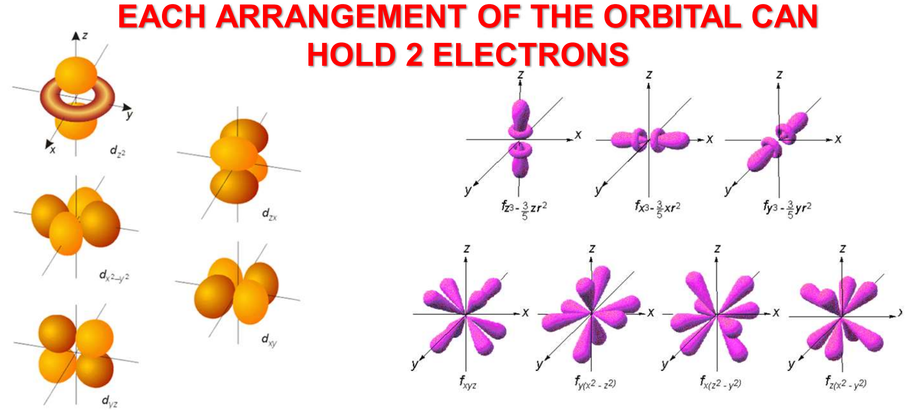
Putting it Together



EACH ARRANGEMENT OF THE ORBITAL CAN HOLD 2 ELECTRONS



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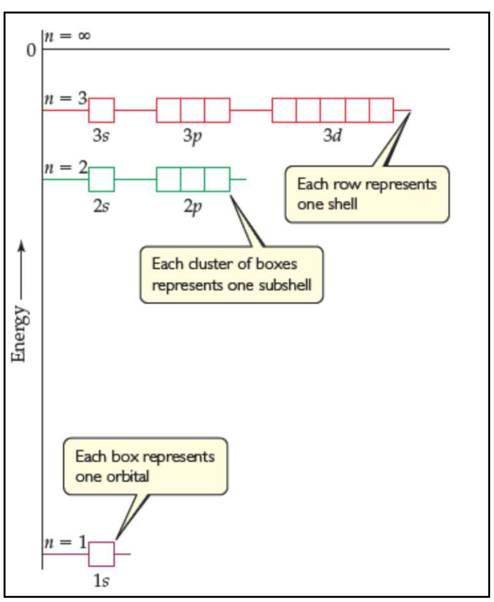
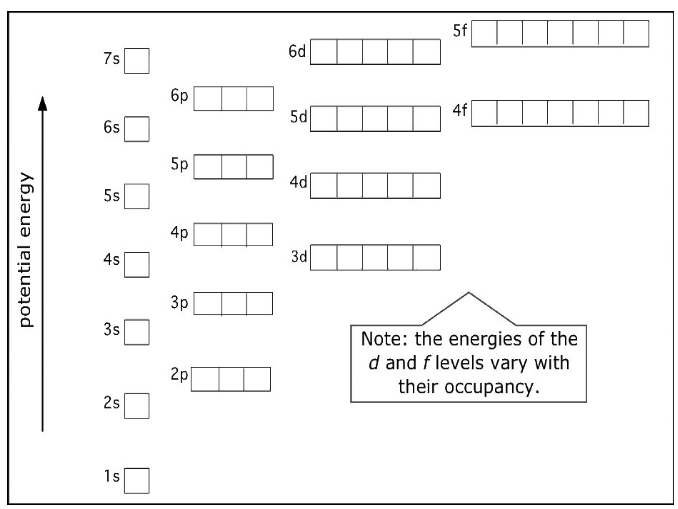




OTHER CONSIDERATIONS

2. Aufbau Principle

WOLFGANG PAULI

Electrons always fill the lowest energy orbitals first.

OTHER CONSIDERATIONS

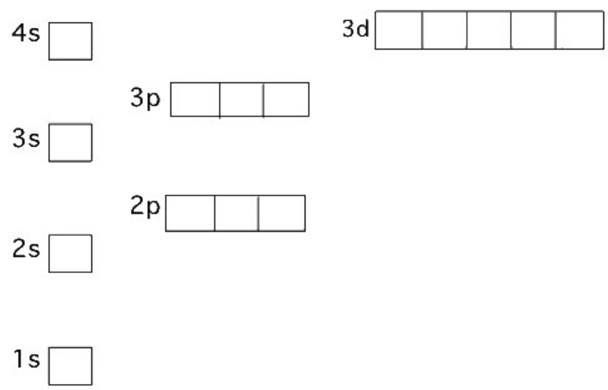
3. Hund's Rule

FRIEDRICH HUND

Electrons only pair up in orbitals after every orbital contains single electrons.

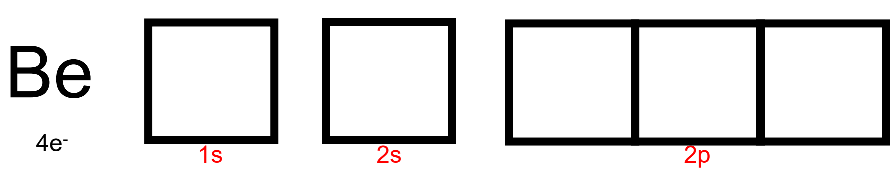
VERTICAL ORBITAL DIAGRAMS

Determine the electron configuration for <u>carbon</u>.



HORIZONTAL ORBITAL DIAGRAMS

Write carbon's electron configuration in a horizontal diagram.

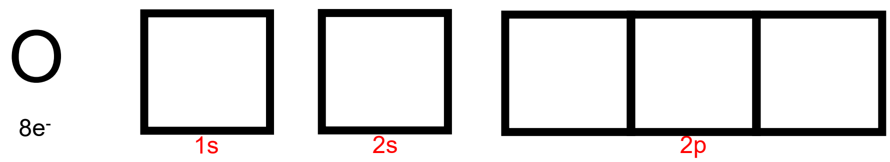


An atom will either gain electrons to fill half-filled orbitals in an energy level or lose electrons to empty an energy level.

SUBLEVEL NOTATION

Write the electron configuration for oxygen in sublevel notation.

Horizontal Notation:

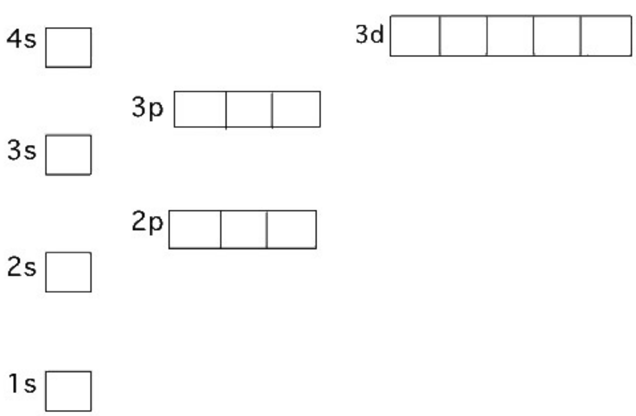


Sublevel Notation:

How many electrons does an oxygen atom need to gain or lose to achieve a stable electron configuration?

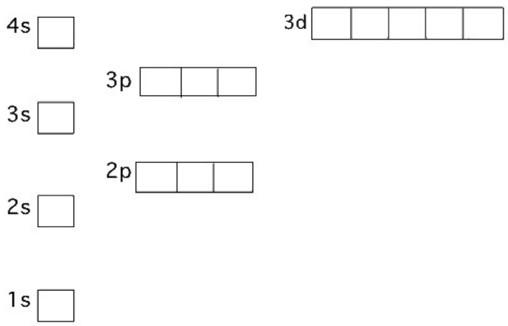
VALENCE ELECTRONS

Complete the orbital energy diagram below for iron and then write its electron configuration in sublevel notation. How many valence electrons does iron possess? How many unpaired electrons does it possess?



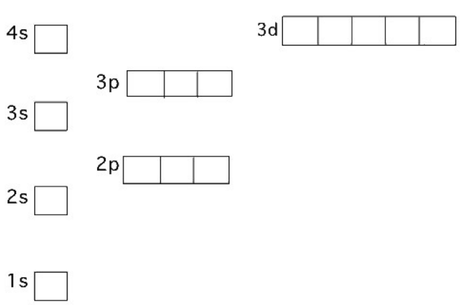
ION SUBLEVEL NOTATION

Write the electron configuration for a chloride **ion** in sublevel notation.



ION SUBLEVEL NOTATION

Write the electron configuration for a manganese **ion** in sublevel notation.



SUMMARY

Energy Level	Sub-Energy Levels	Orbitals	Electrons in Each Orbital	Number of Electrons in Each Sub-Energy Level	Total Electrons in Energy Level
1	1s	1 s,	2	2	2
2	2s, 2p	1 s, 3 p's	2	2, 6	8
3	3s, 3p, 3d	1 s, 3 p's, 5 d's	2	2, 6, 10	18
4	4s, 4p, 4d, 4f	1 s, 3 p's, 5 d's, 7 f's	2	2, 6, 10, 14	32

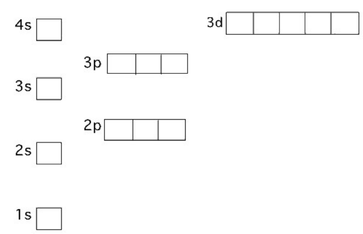
4. THE PERIODIC TABLE & ELECTRONS

CH40S UNIT 5 – ATOMIC STRUCTURE MR. WIEBE

1

REVIEW QUIZ…

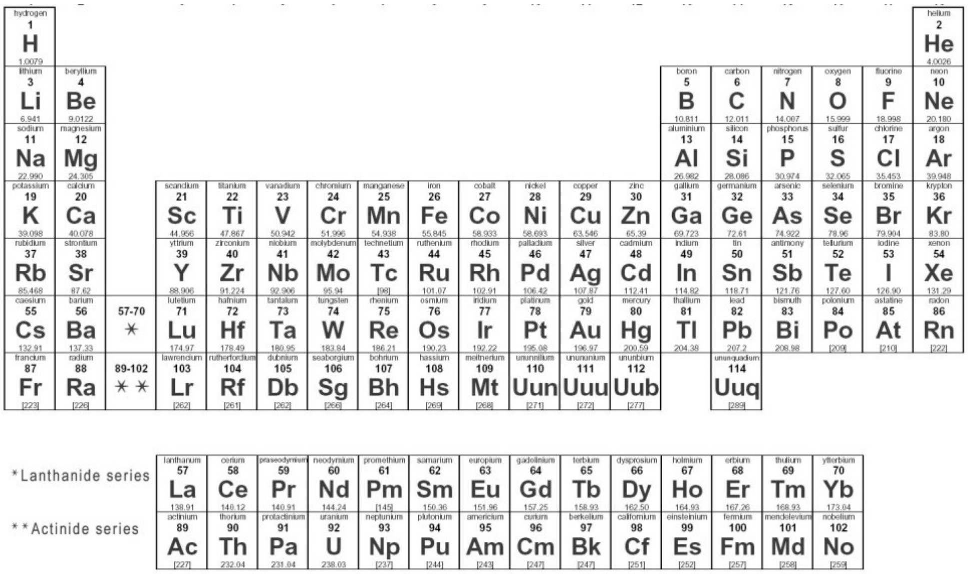
1. Write the sublevel notation electron configuration for an atom of copper (Cu).
2. Circle the valence electrons in your sublevel notation.
3. How many unpaired electrons are found in an atom of copper? Is copper magnetic or not?
4. Predict the most common ion of copper from your electron configuration. Write the electron configuration of this ion.



Slide 2

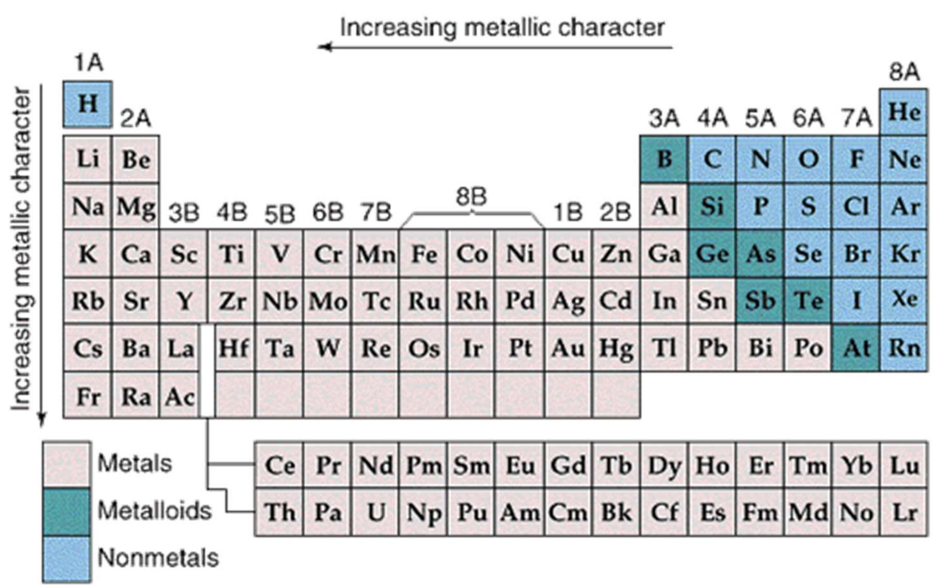
2

PERIODIC TABLE - BASIC ORGANIZATION



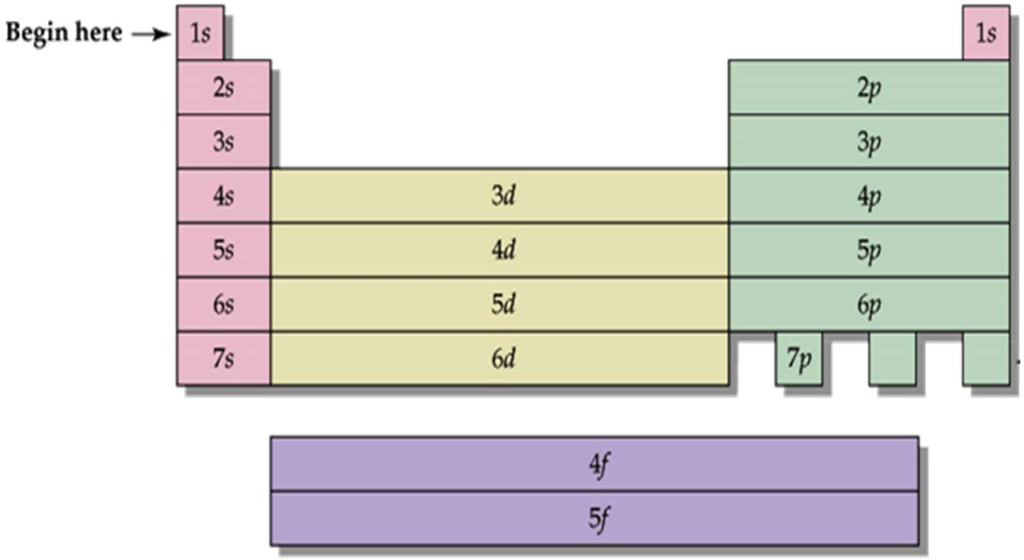
3

PERIODIC TABLE - HIDDEN PATTERNS



4

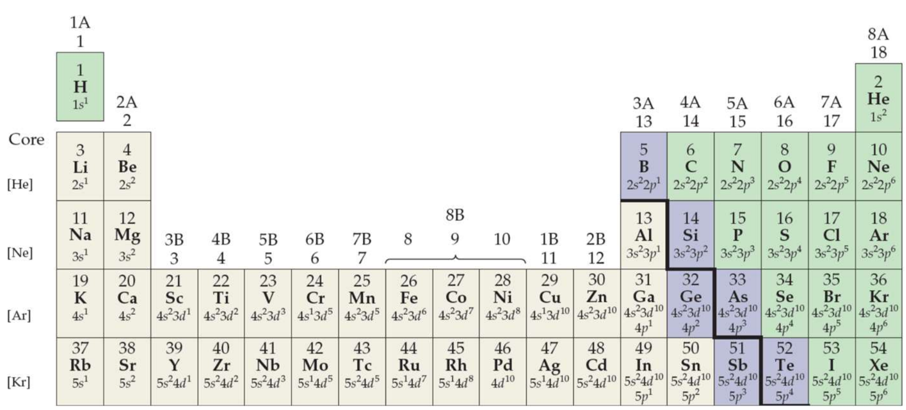
THE BEAUTY OF THE PERIODIC TABLE



5

THE BEAUTY OF THE PERIODIC TABLE

The last electrons in the electron configuration correspond to the placement of the element in its specific "block".



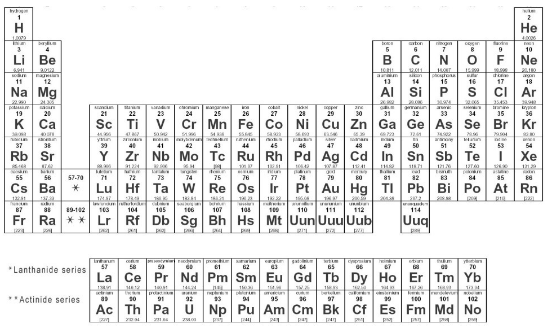
<u>For example - Magnesium</u>

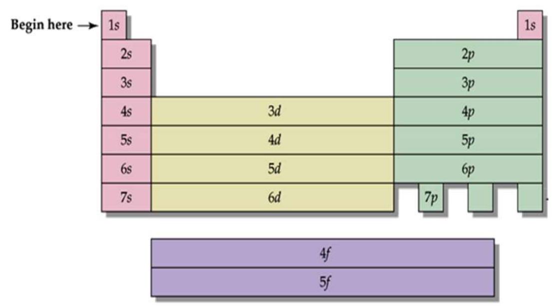
[Ne] **$3s^2$** and found **2 jumps across** the **3^{rd} period** in the **s-block**!

6

SUBLEVEL NOTATION – COMPLETE CONFIGURATION

Zinc (Zn)

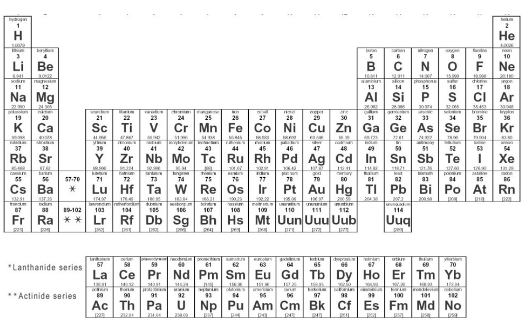


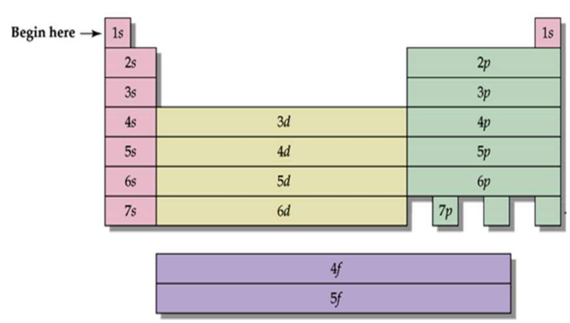


7

SUBLEVEL NOTATION – NOBLE GAS CONGIGURATION

Platinum (Pt)





8

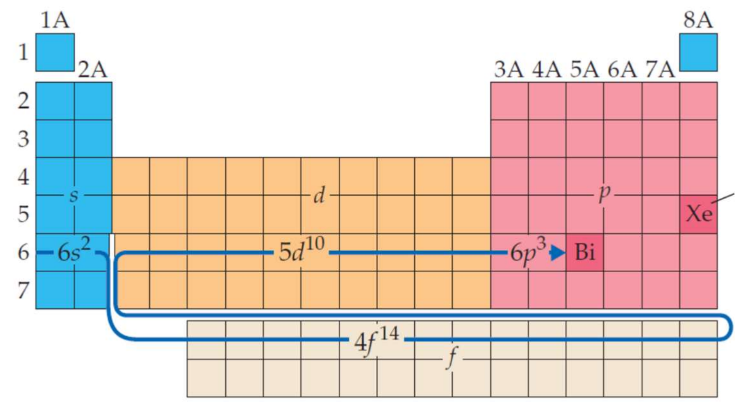
5. PERIODIC PROPERTIES OF ELEMENTS

CH40S UNIT 5 – ATOMIC STRUCTURE MR. WIEBE

1

REVIEW

What is the electron configuration of bismuth (Bi) in noble gas notation?



2

THE "PERIODIC" TABLE

"**<u>Periodicity</u>**" :

refers to similarities in behavior and reactivity due to similar outer shell electron configurations.

<u>For example</u>:

- ✓All Alkali Metals have one half-filled s-orbital
- ✓All Noble Gases have completely filled p-orbitals.

3

PERIODICITY OF ELECTRON CONFIGURATIONS

Core	1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
	1 **H** $1s^1$																	2 **He** $1s^2$
[He]	3 **Li** $2s^1$	4 **Be** $2s^2$											5 **B** $2s^22p^1$	6 **C** $2s^22p^2$	7 **N** $2s^22p^3$	8 **O** $2s^22p^4$	9 **F** $2s^22p^5$	10 **Ne** $2s^22p^6$
[Ne]	11 **Na** $3s^1$	12 **Mg** $3s^2$											13 **Al** $3s^23p^1$	14 **Si** $3s^23p^2$	15 **P** $3s^23p^3$	16 **S** $3s^23p^4$	17 **Cl** $3s^23p^5$	18 **Ar** $3s^23p^6$
[Ar]	19 **K** $4s^1$	20 **Ca** $4s^2$	21 **Sc** $4s^23d^1$	22 **Ti** $4s^23d^2$	23 **V** $4s^23d^3$	24 **Cr** $4s^13d^5$	25 **Mn** $4s^23d^5$	26 **Fe** $4s^23d^6$	27 **Co** $4s^23d^7$	28 **Ni** $4s^23d^8$	29 **Cu** $4s^13d^{10}$	30 **Zn** $4s^23d^{10}$	31 **Ga** $4s^23d^{10}4p^1$	32 **Ge** $4s^23d^{10}4p^2$	33 **As** $4s^23d^{10}4p^3$	34 **Se** $4s^23d^{10}4p^4$	35 **Br** $4s^23d^{10}4p^5$	36 **Kr** $4s^23d^{10}4p^6$
[Kr]	37 **Rb** $5s^1$	38 **Sr** $5s^2$	39 **Y** $5s^24d^1$	40 **Zr** $5s^24d^2$	41 **Nb** $5s^24d^3$	42 **Mo** $5s^14d^5$	43 **Tc** $5s^24d^5$	44 **Ru** $5s^14d^7$	45 **Rh** $5s^14d^8$	46 **Pd** $4d^{10}$	47 **Ag** $5s^14d^{10}$	48 **Cd** $5s^24d^{10}$	49 **In** $5s^24d^{10}5p^1$	50 **Sn** $5s^24d^{10}5p^2$	51 **Sb** $5s^24d^{10}5p^3$	52 **Te** $5s^24d^{10}5p^4$	53 **I** $5s^24d^{10}5p^5$	54 **Xe** $5s^24d^{10}5p^6$

4

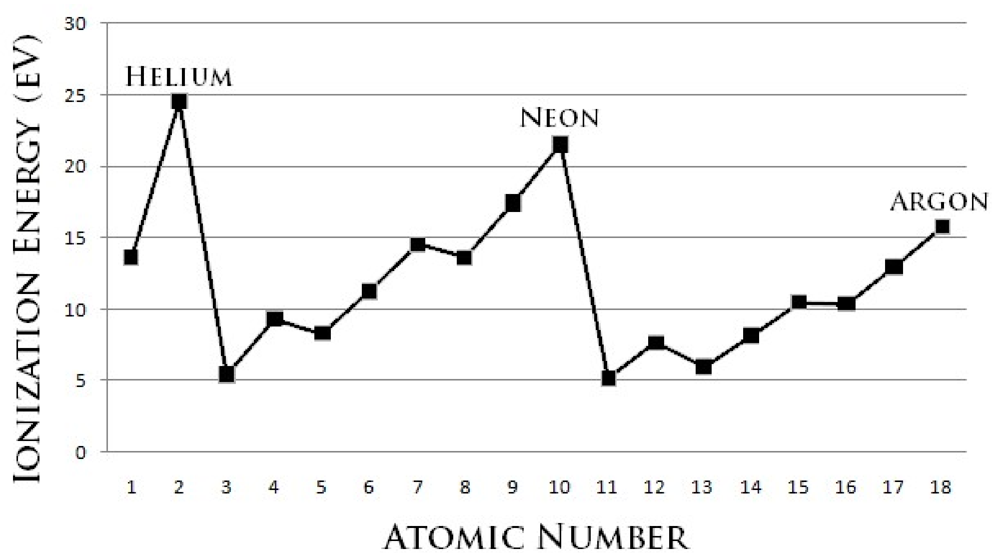
TRENDS IN ATOMIC PROPERTIES -DEFINITIONS

<u>Ionization Energy</u> — the energy required to <u>remove</u> the last electron from an atom

<u>Atomic Radius</u> — Distance from nucleus to the outermost orbital in an atom (pretty much…)

5

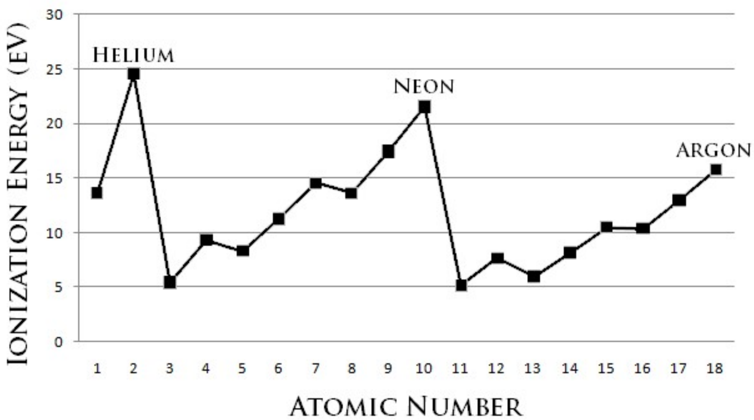
IONIZATION ENERGY



6

IONIZATION ENERGY

Tends to INCREASE across a period



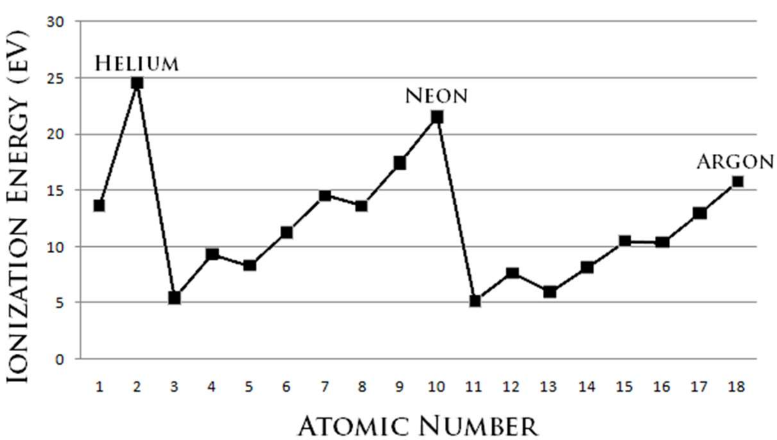
Explanation:

Number of protons in nucleus increases, the attraction to valence increases, harder to remove. (Coulomb's Law)

7

IONIZATION ENERGY

Tends to DECREASE down a group

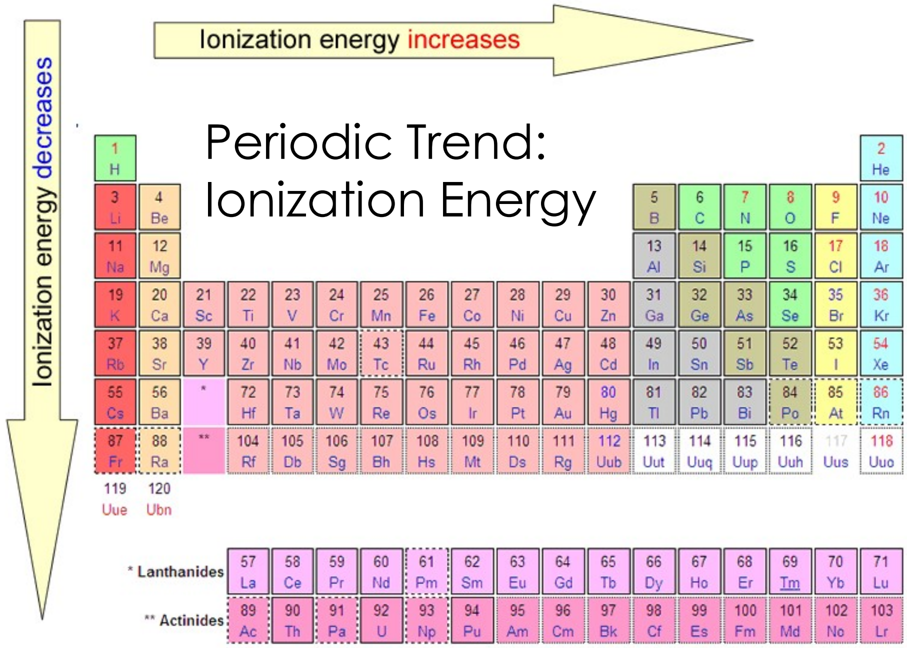


Explanation:

Outer electrons are farther from the nucleus, have less attraction and are easier to remove. (Coulomb's Law)

8

Periodic Trend: Ionization Energy

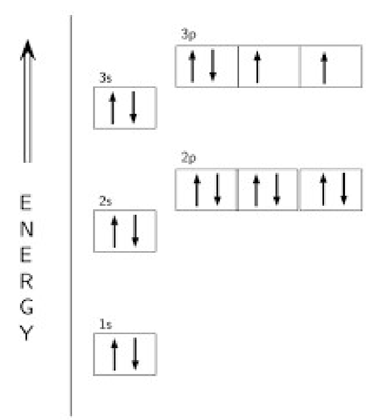


9

SUCCESSIVE IONIZATION ENERGIES - SULPHUR

Element	I_1	I_2	I_3	I_4	I_5	I_6	I_7
S	1000	2252	3357	4556	7004	8496	27,107

- Every time an electron is removed from an orbital in a specific energy level, the remaining valence electrons have less repulsion and more attraction to nucleus.
- This makes subsequent electrons harder to remove, causing an increase in ionization energy.

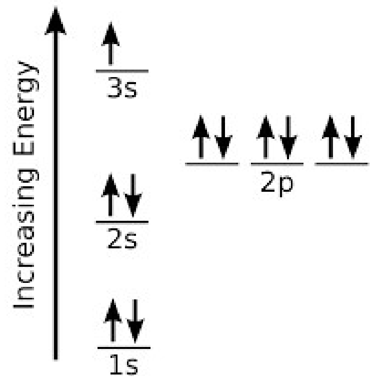


10

SUCCESSIVE IONIZATION ENERGIES - SODIUM

Element	I_1	I_2
Na	496	4562

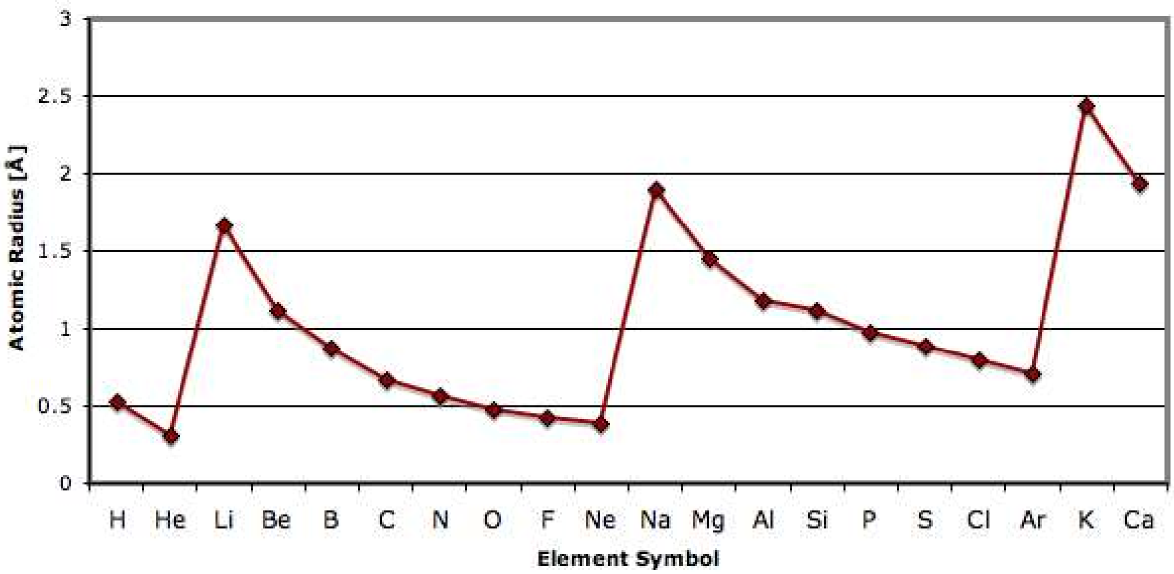
- It is much harder to remove sodiums second outer electron since it is in a lower energy level, much close to the nucleus.



1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
496	4562	6912	9543	13353	16610	20114	25490	28933	141360	159074

11

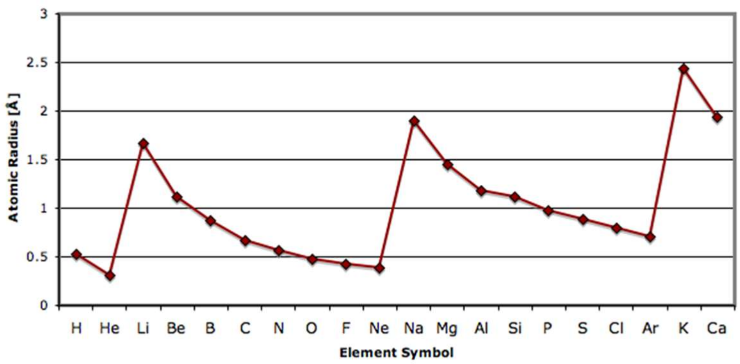
ATOMIC RADIUS



12

ATOMIC RADIUS

Radius INCREASE down a group



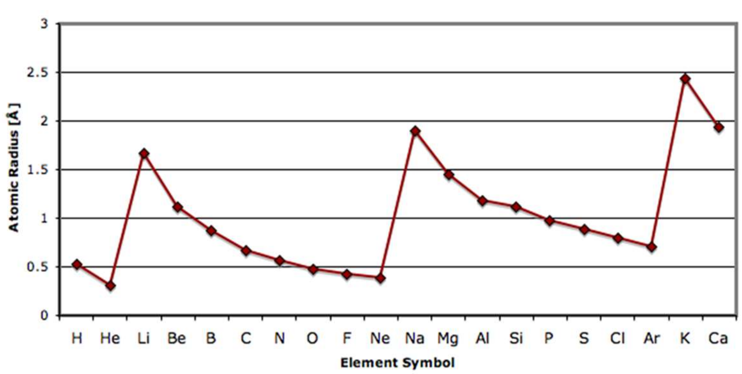
Explanation:

Each row on the periodic table adds a new energy level to the atom further from the nucleus.

13

ATOMIC RADIUS

Radius DECREASE across a period

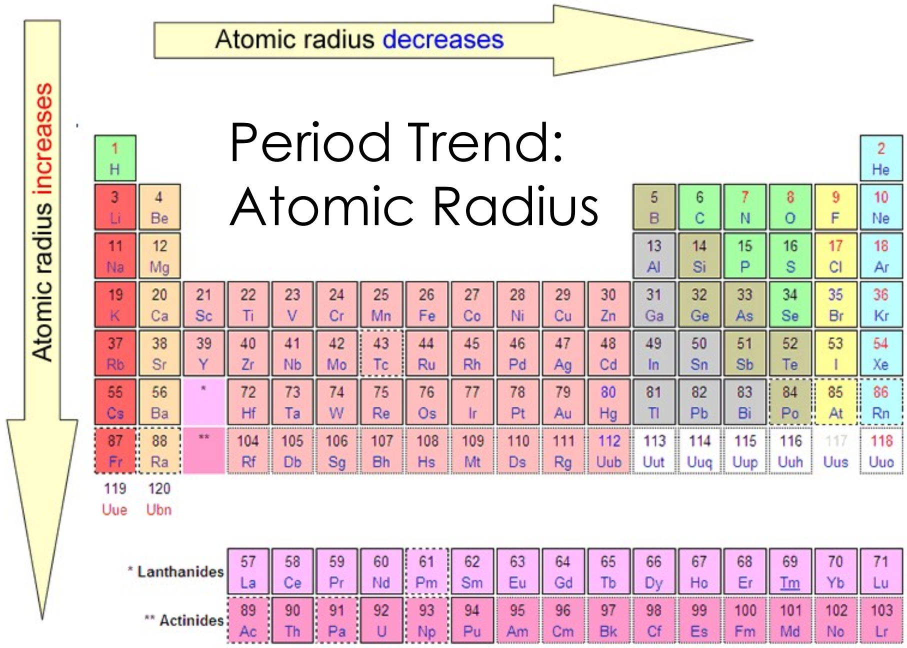


Explanation:

Number of protons in nucleus increases, increasing attraction & causing the electrons to get "pulled in".

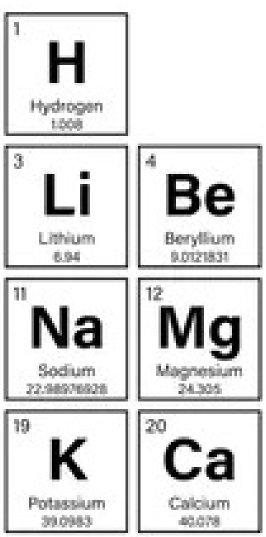
14

Period Trend: Atomic Radius



15

WATCH THIS…



Potassium is (more/less) reactive than sodium? Why?

Calcium is (more/less) reactive than potassium? Why?

16

CHALLENGE

Use the following collection of elements to answer the following questions:

Sodium, sulphur, calcium, chlorine, argon, potassium

1. Arrange the elements in order of increasing atomic radius.
2. Arrange the elements in order of decreasing ionization energy.
3. Potassium is more reactive than sodium. Give one possible explanation for this.
4. Calcium is less reactive than potassium. Give one possible explanation for this.

17

Periodic Chart of Ions

Table of Polyatomic Ions

acetate	CH_3COO^-	dichromate	$Cr_2O_7^{2-}$	dihydrogen phosphate	$H_2PO_4^-$
ammonium	NH_4^+	cyanide	CN^-	silicate	SiO_3^{2-}
benzoate	$C_6H_5COO^-$	hydroxide	OH^-	sulphate	SO_4^{2-}
borate	BO_3^{3-}	iodate	IO_3^-	sulphite	SO_3^{2-}
carbonate	CO_3^{2-}	nitrate	NO_3^-	hydrogen sulphide	HS^-
hydrogen carbonate	HCO_3^-	nitrite	NO_2^-	hydrogen sulphate	HSO_4^-
chlorate	ClO_3^-	oxalate	$OOCCOO^{2-}$	hydrogen sulphite	HSO_3^-
hypochlorite	ClO^-	permanganate	MnO_4^-	thiocyanate	SCN^-
chromate	CrO_4^{2-}	phosphate	PO_4^{3-}	thiosulphate	$S_2O_3^{2-}$
		hydrogen phosphate	HPO_4^{2-}		

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H^+ hydrogen																	2 He helium
3 Li^+ lithium	4 Be^{2+} Beryllium											5 B boron	6 C carbon	7 N^{3-} nitride	8 O^{2-} oxide	9 F^- fluoride	10 Ne neon
11 Na^+ sodium	12 Mg^{2+} magnesium											13 Al^{3+} aluminum	14 Si silicon	15 P^{3-} phosphide	16 S^{2-} sulfide	17 Cl^- chloride	18 Ar argon
19 K^+ potassium	20 Ca^{2+} calcium	21 Sc^{3+} scandium	22 Ti^{4+} titanium (IV) Ti^{3+} titanium (III)	23 V^{5+} vanadium (V) V^{4+} vanadium (IV)	24 Cr^{3+} chromium (III) Cr^{2+} chromium (II)	25 Mn^{2+} manganese (II) Mn^{4+} manganese (IV)	26 Fe^{3+} iron (III) Fe^{2+} iron (II)	27 Co^{2+} cobalt (II) Co^{3+} cobalt (III)	28 Ni^{2+} nickel (II) Ni^{3+} nickel (III)	29 Cu^{2+} copper (II) Cu^+ copper (I)	30 Zn^{2+} zinc	31 Ga^{3+} gallium	32 Ge^{4+} germanium	33 As^{3-} arsenide	34 Se^{2-} selenide	35 Br^- bromide	36 Kr krypton
37 Rb^+ rubidium	38 Sr^{2+} strontium	39 Y^{3+} yttrium	40 Zr^{4+} zirconium	41 Nb^{5+} niobium (V) Nb^{3+} niobium (III)	42 Mo^{6+} molybdenum	43 Tc^{7+} technetium	44 Ru^{3+} ruthenium (III) Ru^{4+} ruthenium (IV)	45 Rh^{3+} rhodium	46 Pd^{2+} paladium (II) Pd^{4+} paladium (IV)	47 Ag^+ silver	48 Cd^{2+} cadmium	49 In^{3+} indium	50 Sn^{4+} tin (IV) Sn^{2+} tin (II)	51 Sb^{3+} antimony (III) Sb^{5+} antimony (V)	52 Te^{2-} telluride	53 I^- iodide	54 Xe xenon
55 Cs^+ cesium	56 Ba^{2+} barium	57 La^{3+} lanthanum	72 Hf^{4+} hafnium	73 Ta^{5+} tantalum	74 W^{6+} tungsten	75 Re^{7+} rhenium	76 Os^{4+} osmium	77 Ir^{4+} iridium	78 Pt^{4+} platinum (IV) Pt^{2+} platinum (II)	79 Au^{3+} gold (III) Au^+ gold (I)	80 Hg^{2+} mercury (II) Hg^+ mercury (I)	81 Tl^+ thallium (I) Tl^{3+} thallium (III)	82 Pb^{2+} lead (II) Pb^{4+} lead (IV)	83 Bi^{3+} bismuth (III) Bi^{5+} bismuth (V)	84 Po^{2+} polonium (II) Po^{4+} polonium (IV)	85 At^- astatide	86 Rn radon
87 Fr^+ francium	88 Ra^{2+} radium	89 Ac^{3+} actinium															

KEY

atomic number	26
symbol / ion charge / stock name (IUPAC)	Fe^{3+} iron (III)
symbol	Fe^{2+} iron (II)

58 Ce^{3+} cerium	59 Pr^{3+} praseodymium	60 Nd^{3+} neodymium	61 Pm^{3+} promethium	62 Sm^{3+} samarium (III) Sm^{2+} samium(II)	63 Eu^{3+} europium (III) Eu^{2+} europium(II)	64 Gd^{3+} gadolinium	65 Tb^{3+} terbium	66 Dy^{3+} dysprosium	67 Ho^{3+} holmium	68 Er^{3+} erbium	69 Tm^{3+} thulium	70 Yb^{3+} ytterbium (III) Yb^{2+} ytterbium (II)	71 Lu lutetium
90 Th^{4+} thorium	91 Pa^{5+} protactinium (V) Pa^{4+} protactinium(IV)	92 U^{6+} uranium (VI) U^{4+} uranium (IV)	93 Np^{5+} neptunium	94 Pu^{4+} plutonium (IV) Pu^{6+} plutonium (VI)	95 Am^{3+} americium (III) Am^{4+} americium (IV)	96 Cm^{3+} curium	97 Bk^{3+} berkelium (III) Bk^{4+} berkelium (IV)	98 Cf^{3+} californium	99 Es^{3+} einsteinium	100 Fm^{3+} fermium	101 Md^{2+} mendelevium(II) Md^{3+} mendelevium (III)	102 No^{2+} nobelium (II) No^{3+} nobelium (III)	103 Gd^{3+} lawrencium

Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** Hydrogen 1.0																	2 **He** Helium 4.0
3 **Li** Lithium 6.9	4 **Be** Beryllium 9.0											5 **B** Boron 10.8	6 **C** Carbon 12.0	7 **N** Nitrogen 14.0	8 **O** Oxygen 16.0	9 **F** Fluorine 19.0	10 **Ne** Neon 20.2
11 **Na** Sodium 23.0	12 **Mg** Magnesium 24.3											13 **Al** Aluminum 27.0	14 **Si** Silicon 28.1	15 **P** Phosphorus 31.0	16 **S** Sulphur 32.1	17 **Cl** Chlorine 35.5	18 **Ar** Argon 39.9
19 **K** Potassium 39.1	20 **Ca** Calcium 40.1	21 **Sc** Scandium 45.0	22 **Ti** Titanium 47.9	23 **V** Vanadium 50.9	24 **Cr** Chromium 52.0	25 **Mn** Manganese 54.9	26 **Fe** Iron 55.8	27 **Co** Cobalt 58.9	28 **Ni** Nickel 58.7	29 **Cu** Copper 63.5	30 **Zn** Zinc 65.4	31 **Ga** Gallium 69.7	32 **Ge** Germanium 72.6	33 **As** Arsenic 74.9	34 **Se** Selenium 79.0	35 **Br** Bromine 79.9	36 **Kr** Krypton 83.8
37 **Rb** Rubidium 85.5	38 **Sr** Strontium 87.6	39 **Y** Yttrium 88.9	40 **Zr** Zirconium 91.2	41 **Nb** Niobium 92.9	42 **Mo** Molybdenum 95.9	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.1	45 **Rh** Rhodium 102.9	46 **Pd** Palladium 106.4	47 **Ag** Silver 107.9	48 **Cd** Cadmium 112.4	49 **In** Indium 114.8	50 **Sn** Tin 118.7	51 **Sb** Antimony 121.8	52 **Te** Tellurium 127.6	53 **I** Iodine 126.9	54 **Xe** Xenon 131.3
55 **Cs** Cesium 132.9	56 **Ba** Barium 137.3	57 **La** Lanthanum 138.9	72 **Hf** Hafnium 178.5	73 **Ta** Tantalum 180.9	74 **W** Tungsten 183.8	75 **Re** Rhenium 186.2	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.2	78 **Pt** Platinum 195.1	79 **Au** Gold 197.0	80 **Hg** Mercury 200.6	81 **Tl** Thallium 204.4	82 **Pb** Lead 207.2	83 **Bi** Bismuth 209.0	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)									

Key:

14	Atomic Number
Si	Symbol
Silicon	Name
28.1	Atomic Mass

58 **Ce** Cerium 140.1	59 **Pr** Praseodymium 140.9	60 **Nd** Neodymium 144.2	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.4	63 **Eu** Europium 152.0	64 **Gd** Gadolinium 157.3	65 **Tb** Terbium 158.9	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 164.9	68 **Er** Erbium 167.3	69 **Tm** Thulium 168.9	70 **Yb** Ytterbium 173.0	71 **Lu** Lutetium 175.0
90 **Th** Thorium 232.0	91 **Pa** Protactinium 231.0	92 **U** Uranium 238.0	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 (262)

Based on mass of C^{12} at 12.00.

Values in parentheses are the masses of the most stable or best known isotopes for elements which do not occur naturally.