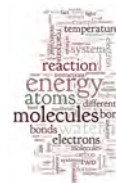


## Quantum Numbers and Atomic Orbitals

CLUE: Chemistry, Life, the Universe & Everything



Energy levels of electrons in an atom are quantized  
(experimental evidence from spectroscopy)

Heisenberg's Uncertainty Principle tells us that  
we can't know both the energy and the position of  
an electron

Particles at the atomic-molecular level have wave-like  
properties (De Broglie)

We use equations derived from quantum mechanics to  
describe both the energy of an electron, and the  
probability of finding that electron in a region of space.

We call these regions of high probability for finding electrons - ATOMIC ORBITALS

and each orbital can be described by a set of quantum numbers - that are derived from quantum mechanical calculations

There are four types of quantum numbers  
 $n$ ,  $\ell$ ,  $m_\ell$ , and  $m_s$

They allow us to understand the arrangement of electrons  
in atoms

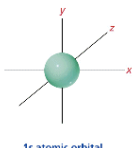
and the arrangement of the periodic table

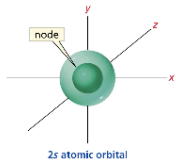
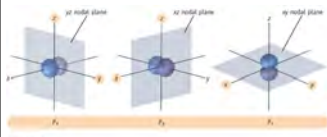
$n$  is the principal quantum number  
it can have values of 1, 2, 3, 4 .....etc

$\ell$  - the angular momentum quantum number  
can have integer values of 0 up to  $n-1$

$m_\ell$  (the magnetic quantum number) can have  
integer values from  $-\ell$  to  $+\ell$   
- that is  $(2\ell + 1)$  values

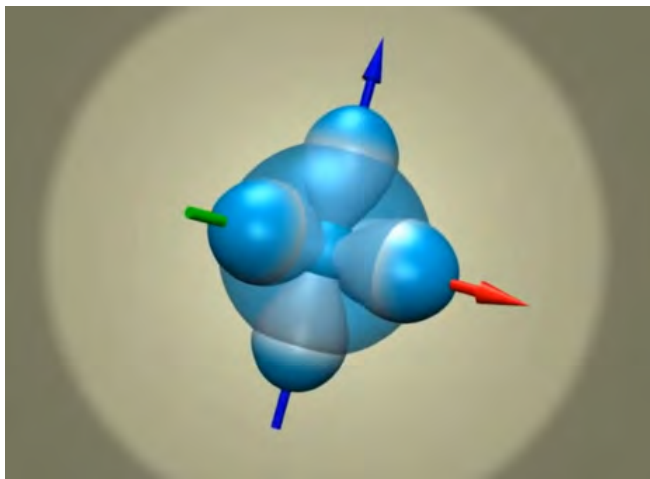
$m_s$  the spin quantum number  
can have values of  $+1/2$  or  $-1/2$

$n$	$\ell$ (0 to $n-1$ )	$m_\ell$ ( $-\ell$ to $+\ell$ )	Orbital type
1	0	0	1s 

n	$\ell$	$m_\ell$	Orbital type
2	0	0	<div>  <p>2s</p> <p>2s atomic orbital</p> </div>
	1	1, 0, -1	<div>  <p>2p<sub>x</sub> 2p<sub>y</sub> 2p<sub>z</sub></p> </div>

n	$\ell$	$m_\ell$	Orbital type
3	0	0	3s (like the 2s but with 2 nodes)
	1	1, 0, -1	three 3p orbitals, (like 2p but with 2 nodes)
	2	2, 1, 0, -1, -2	five 3d orbitals

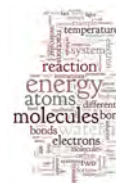
## Video of atomic orbitals



Important consequences  
(why do we need to know this?)

Understanding the idea that electrons can be described by orbitals of different shapes and definite energies – allows us to understand how elements bond and react, and the arrangement of the periodic table.

CLUE: Chemistry, Life, the Universe & Everything



## Recap

Each atomic orbital can contain a maximum 2 electrons

We can think of quantum numbers as a set of descriptors for electrons in an atom

Electrons in the same orbital have opposite spins,  
 $m_s = +1/2$  or  $-1/2$

## atomic orbitals and the periodic table

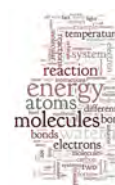
																VIIA																			
																18																			
1 H 1.008																2 He 4.003																			
3 Li 6.941		4 Be 9.012														5 B 10.811		6 C 12.011		7 N 14.007		8 O 15.999		9 F 18.998		10 Ne 20.180									
11 Na 22.990		12 Mg 24.305		13 Al 26.982		14 Si 28.086		15 P 30.974		16 S 32.066		17 Cl 35.453		18 Ar 39.948																					
19 K 39.098		20 Ca 40.078		21 Sc 44.956		22 Ti 47.88		23 V 50.942		24 Cr 51.996		25 Mn 54.938		26 Fe 55.847		27 Co 58.933		28 Ni 58.69		29 Cu 63.546		30 Zn 65.39		31 Ga 69.723		32 Ge 72.61		33 As 74.922		34 Se 78.96		35 Br 79.904		36 Kr 83.80	
37 Rb 85.468		38 Sr 87.62		39 Y 88.906		40 Zr 91.224		41 Nb 92.906		42 Mo 95.94		43 Tc (98)		44 Ru 101.07		45 Rh 102.91		46 Pd 106.42		47 Ag 107.87		48 Cd 112.41		49 In 114.82		50 Sn 118.71		51 Sb 121.75		52 Te 127.60		53 I 126.90		54 Xe 131.29	
55 Cs 132.905		56 Ba 137.327		57 La 138.906		58 Ce 140.12		59 Pr 140.91		60 Nd 144.24		61 Pm (145)		62 Sm 150.36		63 Eu 151.97		64 Gd 157.25		65 Tb 158.93		66 Dy 162.50		67 Ho 164.93		68 Er 167.26		69 Tm 168.93		70 Yb 173.04		71 Lu 174.97			
87 Fr (223)		88 Ra (226)		89 Ac (227)		90 Th (232)		91 Pa (231)		92 U (238)		93 Np (237)		94 Pu (244)		95 Am (243)		96 Cm (247)		97 Bk (247)		98 Cf (251)		99 Es (252)		100 Fm (257)		101 Md (258)		102 No (259)		103 Lr (262)			

Main-group elements																	
s-block		Transition elements												p-block			
1A	2A	d-block										3A	4A	5A	6A	7A	8A
1s																	1s
2s																	2p
3s		3B	4B	5B	6B	7B	8B	1B	2B							3p	
4s																4p	
5s																5p	
6s																6p	
7s																	
Inner-transition elements																	
f-block																	

## Atomic Orbitals and the Periodic Table

[link to video](#)

CLUE: Chemistry, Life, the Universe & Everything

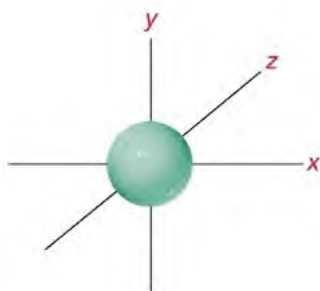


## Recall

The position and energies of electrons in atoms can be described by atomic orbitals

Each atomic orbital can describe a maximum 2 electrons

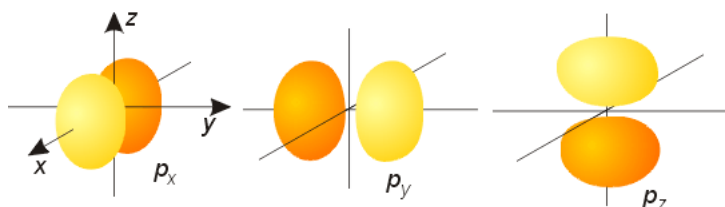
## s orbital



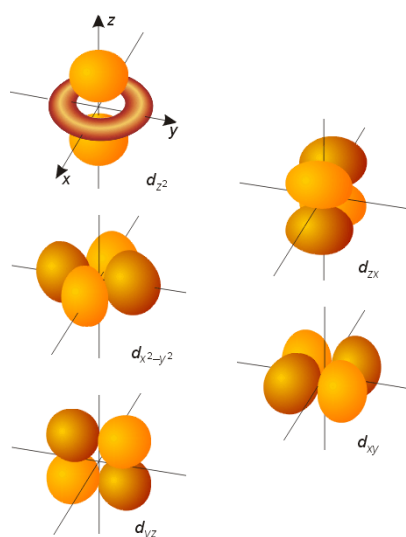
1s atomic orbital



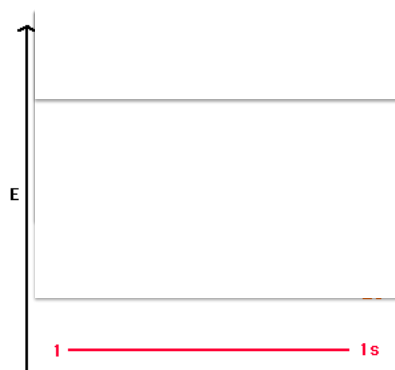
## p orbitals



## d orbitals



Orbitals have different energies



### Atomic orbitals and the periodic table

1s<sup>1</sup>

1s<sup>2</sup>

IA  
1

IIA  
2

IIIA  
13

IVA  
14

VA  
15

VIA  
16

VIIA  
17

VIIIA  
18

1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948										
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	57 La 138.906	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97	
87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th (232.04)	91 Pa (231)	92 U (238.03)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (259)	102 No (259)	103 Lr (262)	

Clemson University

Department of Chemistry

Lanthanides

Actinides

Outer electrons are in the three 2p orbitals

IA 1	IIA 2																	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	VIIIA 18
1 H 1.008	2 He 4.003																	5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3 Li 6.941	4 Be 9.012																	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
11 Na 22.990	12 Mg 24.305	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80						
19 K 39.098	20 Ca 40.078	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc 98	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29						
37 Rb 85.468	38 Sr 87.62	57 La 138.905	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97							
55 Cs 132.905	56 Ba 137.327	87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th (232.04)	91 Pa (231)	92 U (238.03)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)					

Clemson University  
Department of Chemistry

Lanthanides

Actinides

IA 1	IIA 2																	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	VIIIA 18
1 H 1.008	2 He 4.003																	5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3 Li 6.941	4 Be 9.012																	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
11 Na 22.990	12 Mg 24.305	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80						
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29						
55 Cs 132.905	56 Ba 137.327	57 La 138.906	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97							
87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th (232)	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)							

Clemson University

Department of Chemistry

Lanthanides

Actinides

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Clemson University  
Department of Chemistry

**Lanthanides**

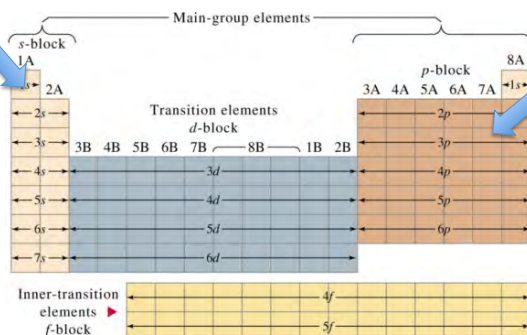
58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
140.12	140.91	144.24	(145)	150.36	151.97	157.25	158.93	162.50	164.93	167.26	168.93	173.04	174.97

**Actinides**

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
232.04	(231)	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(259)	(259)	(262)

We often refer to elements by the location of their electrons in the outermost orbitals

Alkali and alkaline earth metals are part of the "s-block"



Non-metals are part of the "p-block"

## Core and valence electrons

- We are not particularly interested in electron configurations (will not be on exam)
- BUT – core and valence electrons are important!
- Core – is the last noble gas (gp 18) eg Ne or Xe, + any full d shell (transition metals) (a closed shell of electrons is very stable)
- Valence are the electrons that are higher in energy – outside the closed shell

atomic orbitals and the periodic table

# atomic orbitals and the periodic table

[Ne]3s<sup>2</sup>3p<sup>5</sup>  
10 core, 7 valence

[He]2s<sup>2</sup>2p<sup>2</sup>  
2 core, 4 valence

1A 1 H 1.008	2A 2 He 4.003																	18A 18 Ar 39.948
3A 3 Li 6.941	4A 4 Be 9.012											5A 5 B 10.811	6A 6 C 12.011	7A 7 N 14.007	8A 8 O 15.999	9A 9 F 18.998	10A 10 Ne 20.180	
11A 11 Na 22.990	12A 12 Mg 24.305	13A 13 Al 26.982	14A 14 Si 28.086	15A 15 P 30.974	16A 16 S 32.066	17A 17 Cl 35.453	18A 18 Ar 39.948											
19A 19 K 39.098	20A 20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80	
37A 37 Rb 85.468	38A 38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29	
55A 55 Cs 132.905	56A 56 Ba 137.327	57 La 138.906	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97		
87A 87 Fr (223)	88A 88 Ra (226)	89 Ac (227)	90 Th (232)	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (259)	102 No (259)	103 Lr (262)		

Clemson University  
Department of Chemistry

Lanthanides

Actinides

