Pre-AP Chemistry

September 4, 2011

9. Electrons in Atoms III

Review

- Electrons in atoms occupy orbitals described by their quantum numbers.

Quantum Number	Principal	Angular Momentum	Magnetic	Spin
Symbol	n	l	m_l	m_s
Values	1,2,3, …	0,1,2, … (n-1)	-l, 1-l, …, l-1, l	+½, -½
Related To	Distance from Nucleus	Orbital Shape	Orbital Orientation	Magnetic Behavior

- Electrons with the same n are in the same **shell**.
- Electrons with the same n **and** l are in the same **sub-shell**.
- Electrons with the same n **and** l **and** m_l are in the same **orbital**.

Review

- Electrons in atoms occupy orbitals described by their quantum numbers.

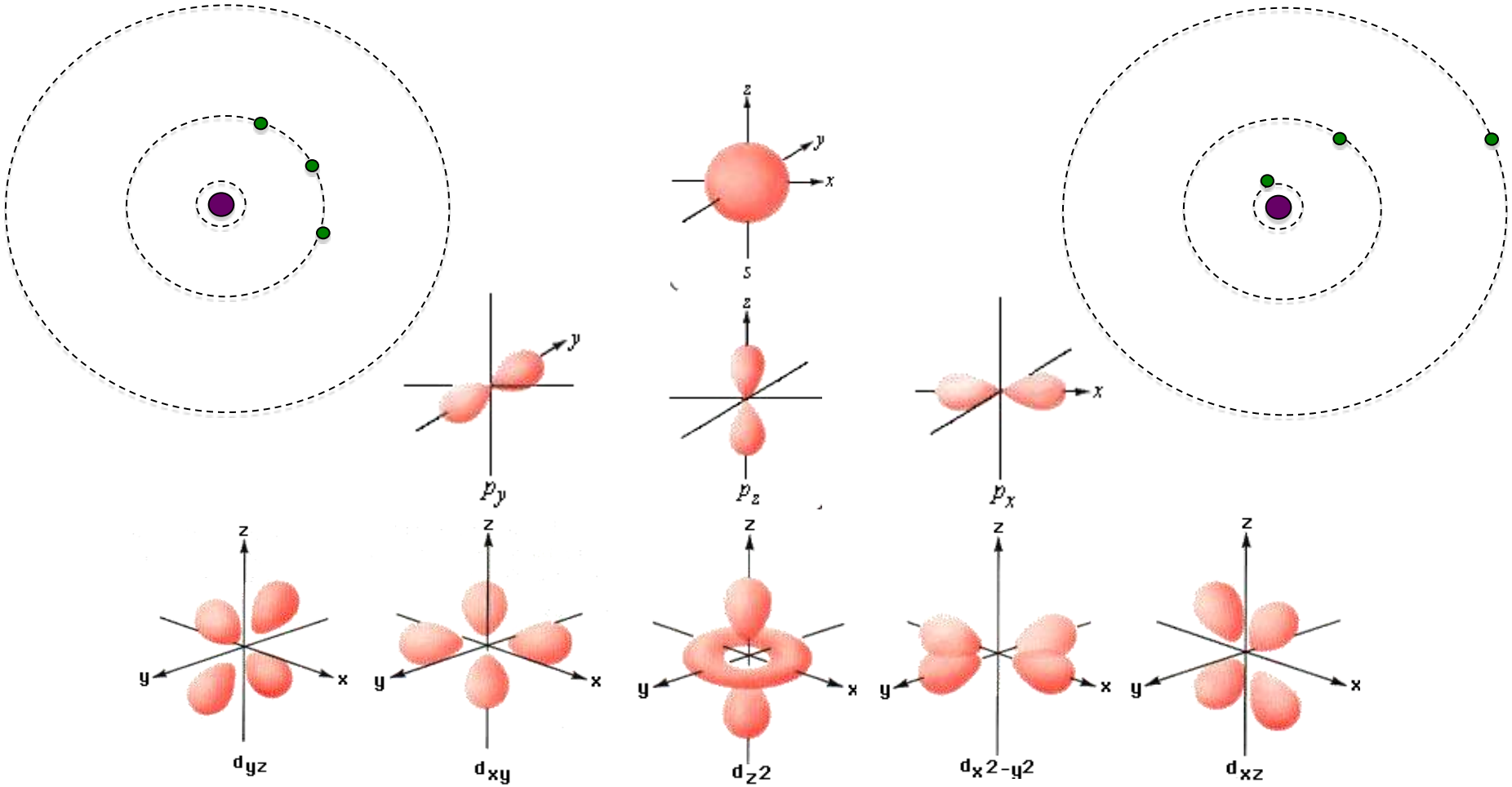
Quantum Number	Principal	Angular Momentum	Magnetic	Spin
Symbol	n	l	m_l	m_s
Values	1,2,3, …	0,1,2, … (n-1)	-l, 1-l, …, l-1, l	+½, -½
Related To	Distance from Nucleus	Orbital Shape	Orbital Orientation	Magnetic Behavior

- Which statement is more accurate?
  1. An n = 3 electron is 100 pm from the nucleus
  2. There is a 90% probability that an n = 3 electron will be found within 100 pm of the nucleus

- Fill in the blanks:
- We cannot know both _____ and _____ with absolute certainty.

Electron Configuration

- What orbitals are occupied by electrons in the **ground states** of different atoms?



Outline

- Electron Configuration (Neutral Atoms)
- Electron Configuration (Ions)

- Electron Configuration (Neutral Atoms)
  - Energy Ordering
  - Pauli Exclusion Principle
  - Hund's Rule
  - Aufbau Process
- Electron Configuration (Ions)
  - Adding Electrons (Making Anions)
  - Removing Electrons (Making Cations)

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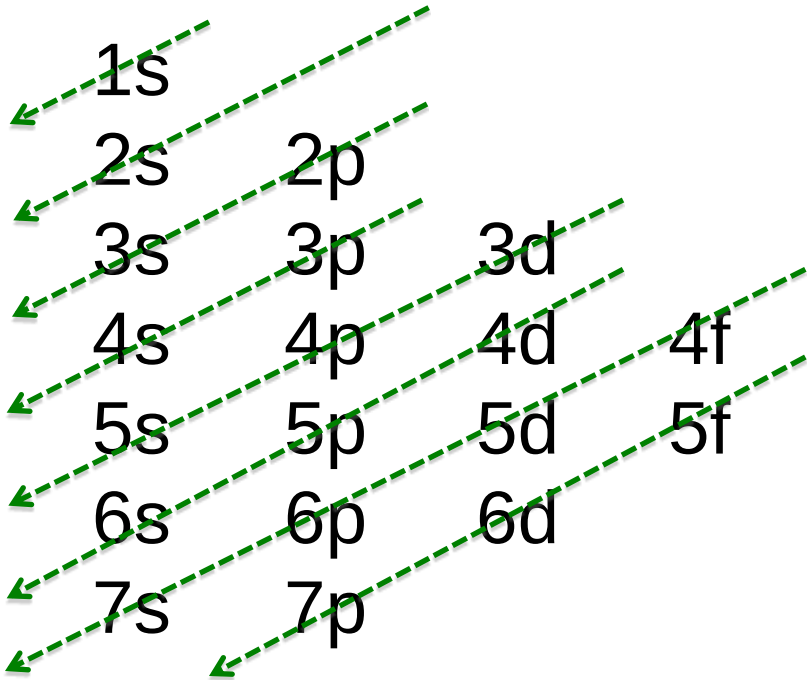
Energy Ordering

- In the ground state, electrons fill orbitals such that the overall energy of the atom is as low as possible
- Different orbitals have different energies

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

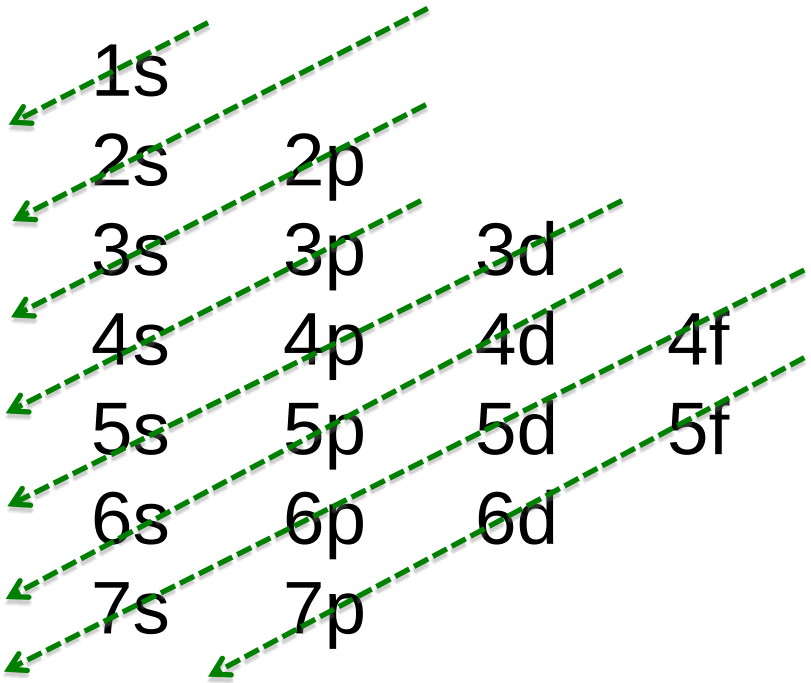
Energy Increasing



Mini Quiz

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

Energy Increasing



H $1s^1$

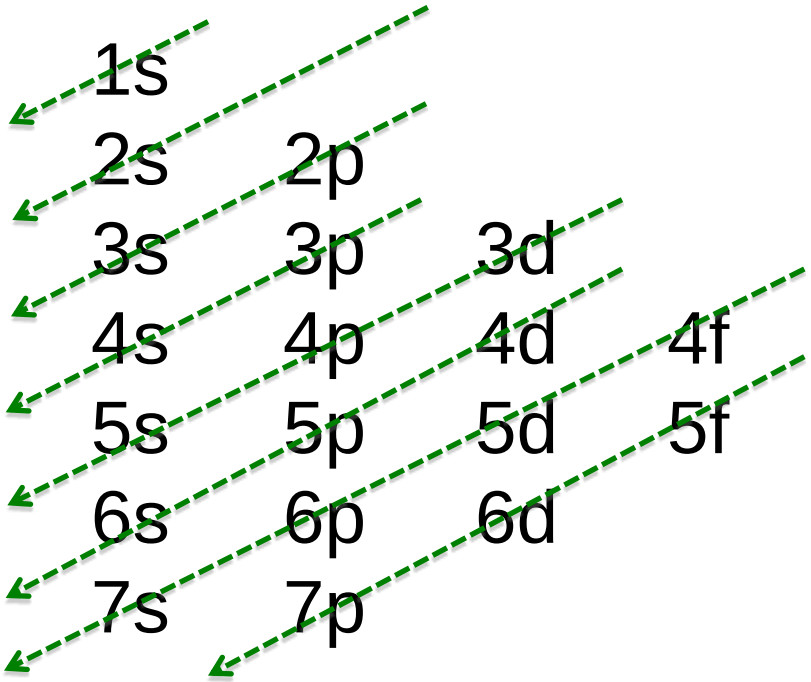
or

H $5d^1$

Mini Quiz

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

Energy Increasing



H $1s^1$

or

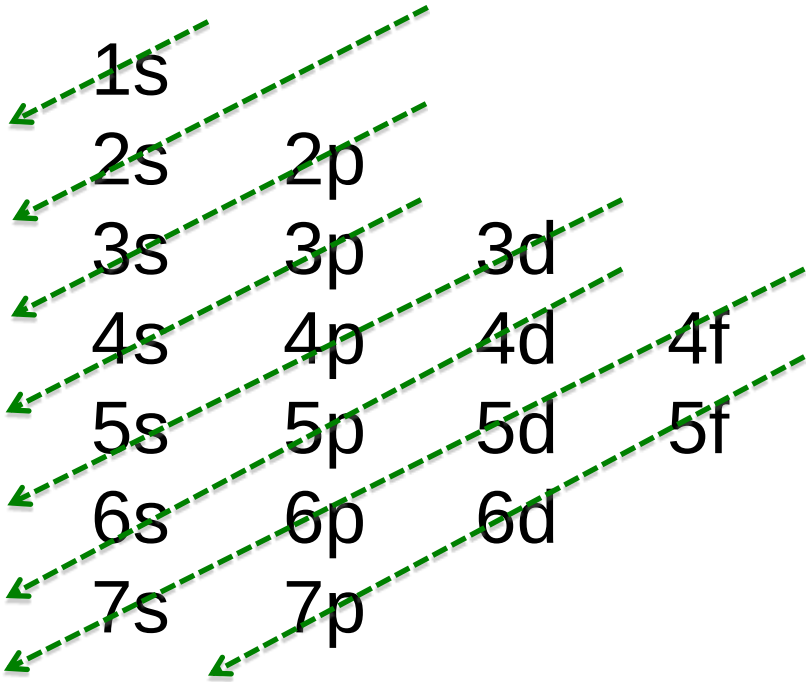
~~**H** $5d^1$~~

Does hydrogen have a 5d orbital?

Mini Quiz

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

Energy Increasing



H $1s^1$

or

~~**H** $5d^1$~~

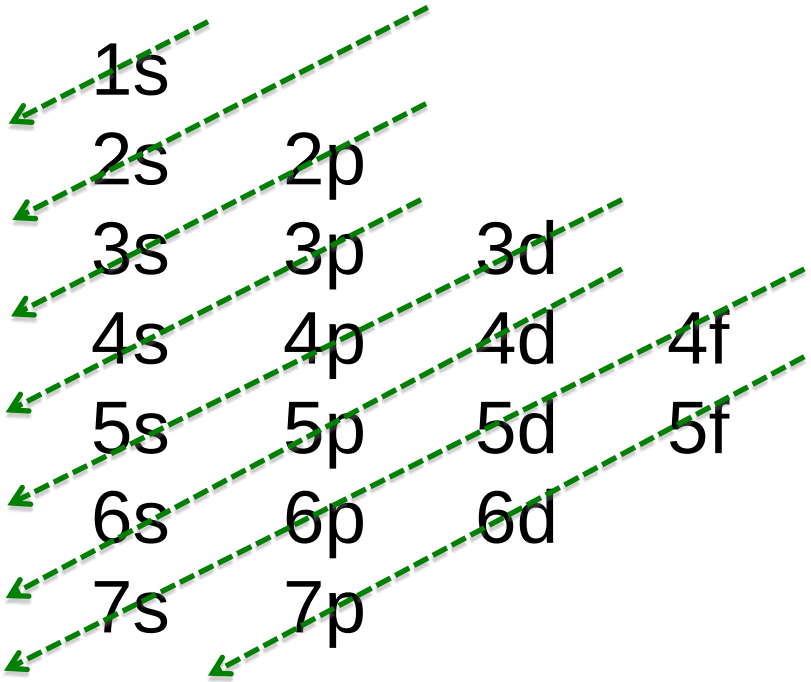
Does hydrogen have a 5d orbital? **YES!**

Is it occupied?

Mini Quiz

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

Energy Increasing



H $1s^1$

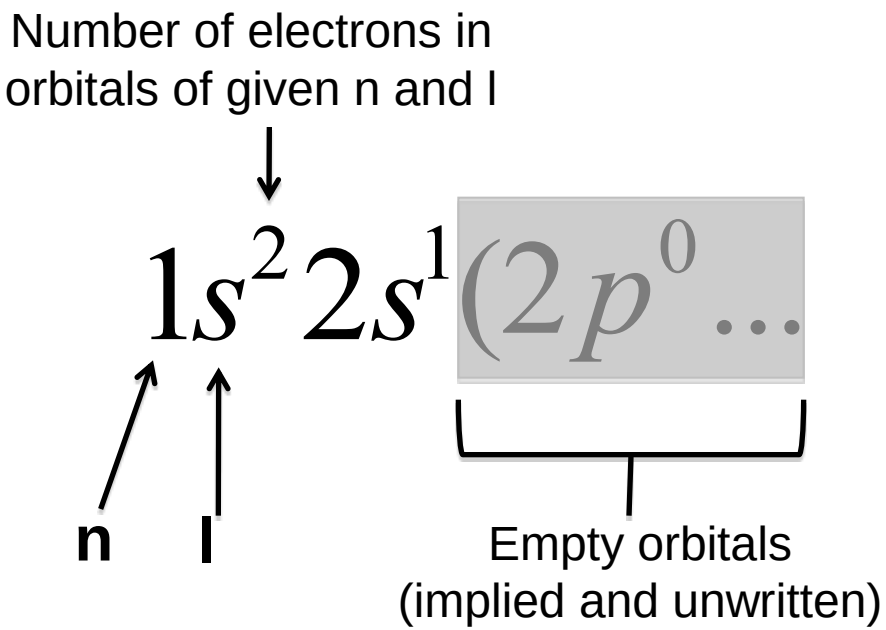
or

~~**H** $5d^1$~~

Does hydrogen have a 5d orbital? **YES!**

Is it occupied? **Not** in the **ground state**

How to Read Electron Configurations



We say: “One ‘s’ two, two ‘s’ one”

H $1s^1$ **B** $1s^2 2s^2 2p^1$ **C** $1s^2 2s^2 2p^2$

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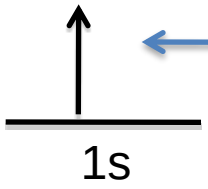
Pauli Exclusion Principle

- **No two electrons** can have the **same four quantum numbers**
- So … No more than two electrons can occupy an orbital
- **Two electrons** occupying the **same orbital** must have **opposite spins**

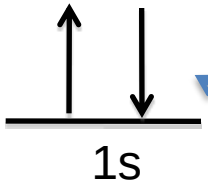
H $1s^1$



n = 1
l = 0
$m_l = 0$
$m_s = + 1/2$

(1,0,0, +1/2)

He $1s^2$



(1,0,0, +1/2)

(1,0,0, -1/2)

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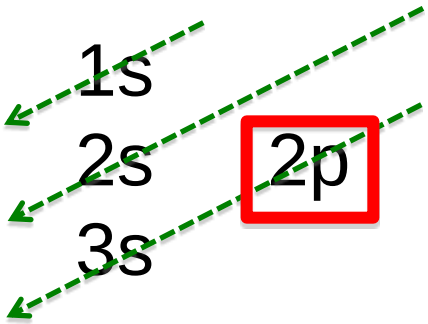
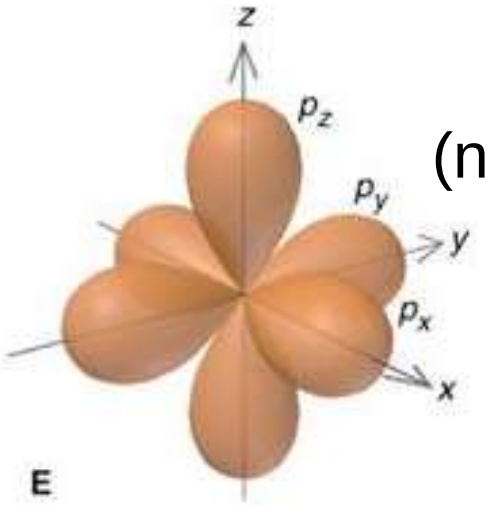
Hund's Rule

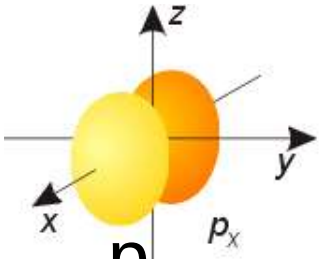
- The **energy of an orbital** only depends on its **principal quantum number** (n) and its **angular momentum quantum number** (l)



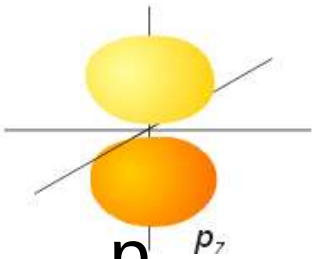


2p
(n = 2, l = 1)

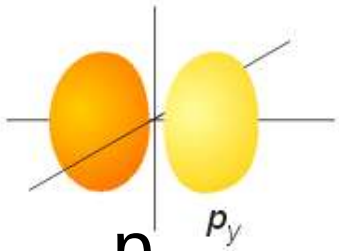
Degenerate Orbitals
(same n and l)



p_x
(ml = -1)



p_z
(ml = 0)



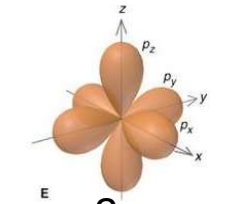
p_y
(ml = +1)

Hund's Rule

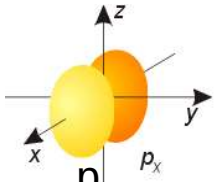
- Electrons fill orbitals with the same energy **one at a time**, with all their **spins** in the **same direction**

B $1s^2 2s^2 2p^1$

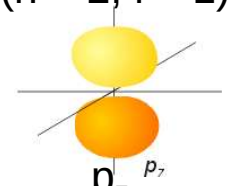
B $1s^2 2s^2 2p_x^1 2p_z^0 2p_y^0$



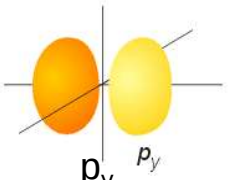
2p
(n = 2, l = 1)



p_x
(ml = -1)



p_z
(ml = 0)



p_y
(ml = +1)

Orbital Diagram

Hund's Rule

B

$1s^2 2s^2 2p^1$

$1s^2 2s^2 2p_x^1 2p_z^0 2p_y^0$

C

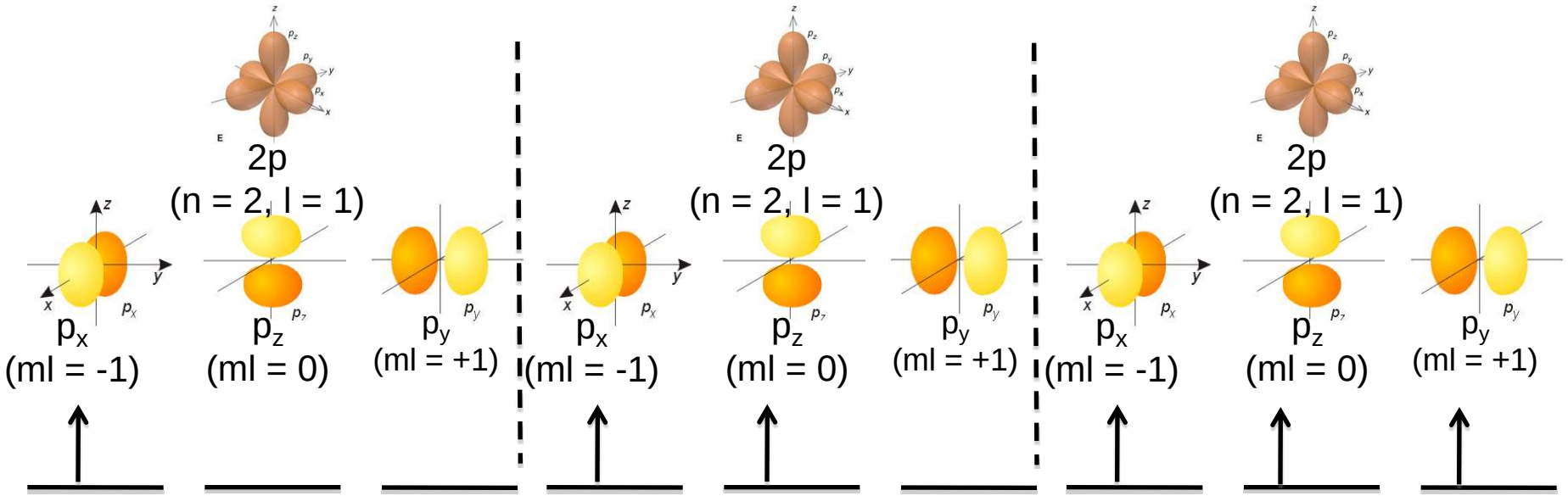
$1s^2 2s^2 2p^2$

$1s^2 2s^2 2p_x^1 2p_z^1 2p_y^0$

N

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

$1s^2 2s^2 2p_x^1 2p_z^1 2p_y^1$



Mini-Quiz

- An atom has electron configuration $1s^2 2s^2 2p^4$. Into what orbital do you predict the next electron will go (assume the atom stays neutral)? What will be the direction of its spin?

- How many electrons can fill an s orbital?
- How many electrons can fill a p orbital?
- For a given l, how many electrons can fill that orbital?

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Aufbau Process

- Aufbau = ‘building up’ in German
- Describes the way in which the ground state electron configurations of different atoms are built
- Let’s go through some examples …

H

- Important: **first step** is always to determine how many **electrons** are in the **neutral atom** and make sure this number **matches** the number of **electrons** in your final **orbital diagram**.

- How many electrons are in **neutral** hydrogen?

- Into what orbital do we place the first electron? Why?

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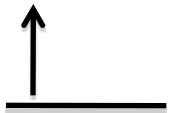
H $1s^1$



1s

- Does it matter that we started with a ‘spin-up’ electron?

- How many electrons can occupy an s orbital?

- What is the spin of the second electron?

- What element has atomic number Z = 2 ?

Aufbau Process

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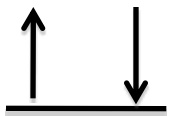
He $1s^2$



1s

- Can we add any more electrons to the 1s orbital?

- What element has atomic number Z = 3?

- Into what orbital do we place the next electron?

Aufbau Process

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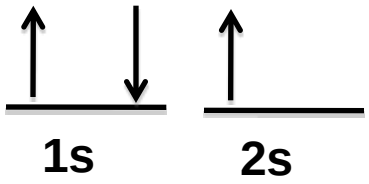
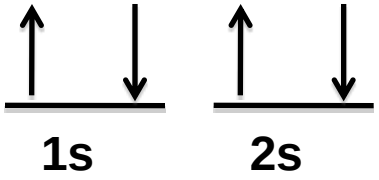
Li $1s^2 2s^1$



Be $1s^2 2s^2$



- What **shell** and **sub-shell** do we fill next?
- How many **orbitals** are in the next **sub-shell**?
- How many electrons can the next **sub-shell** hold?

Aufbau Process

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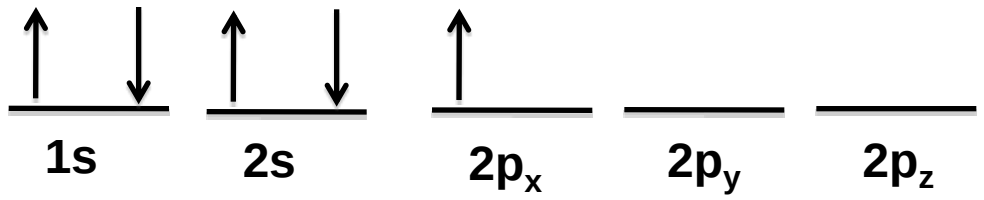
- Describes the way in which the ground state electron configurations of different atoms are built
- Let’s go through some examples …

B $1s^2 2s^2 2p^1$



- What orbital do we fill next?

- What is the spin of the electron in that orbital?

Aufbau Process

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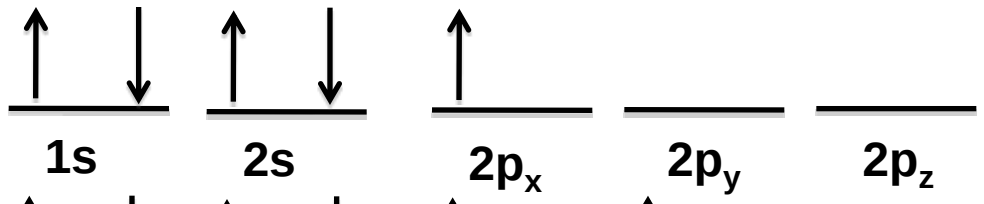
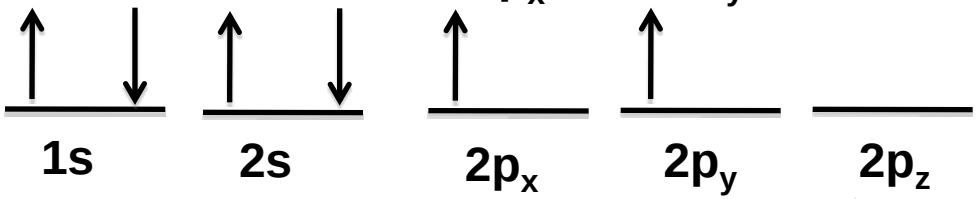
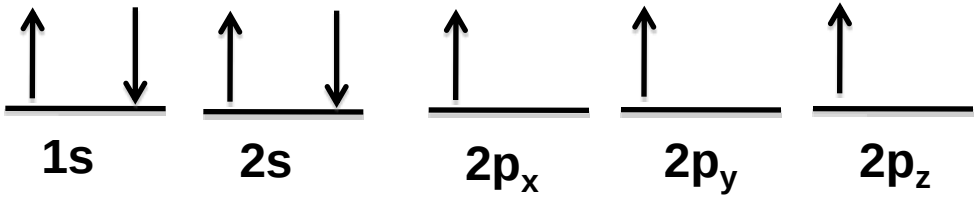
B $1s^2 2s^2 2p^1$



C $1s^2 2s^2 2p^2$



N $1s^2 2s^2 2p^3$



- What orbital do we fill next?

- What is the spin of the electron in that orbital?

Aufbau Process

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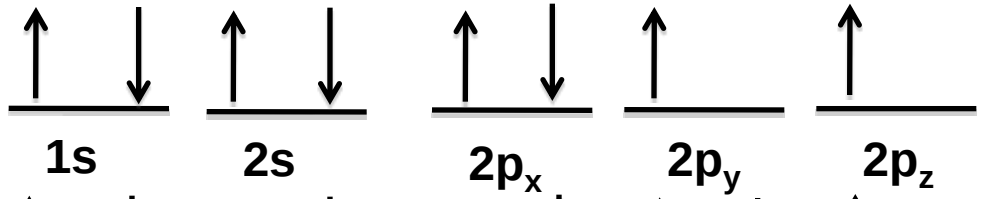
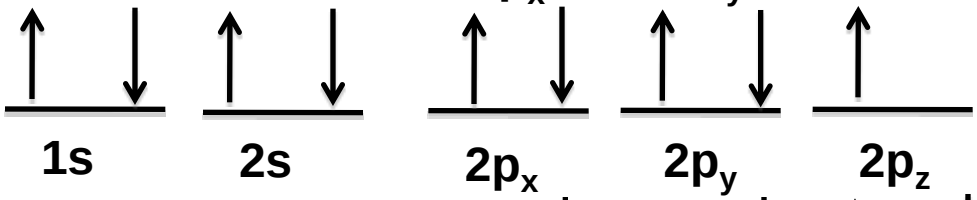
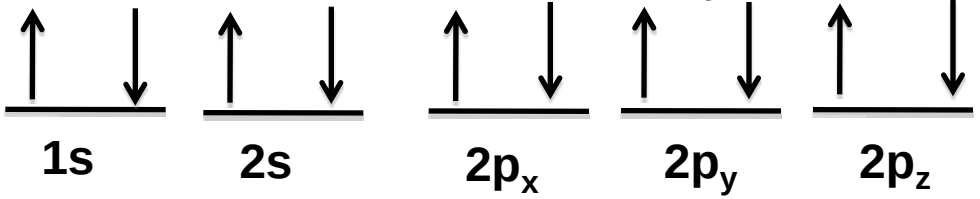
O $1s^2 2s^2 2p^4$



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



Ne $1s^2 2s^2 2p^6$



- What shell and sub-shell do we fill next?

- How many electrons are in that sub-shell?

Aufbau Process

- Aufbau = 'building up' in German
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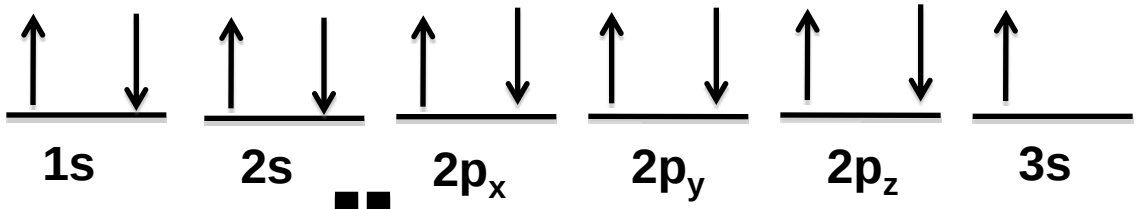
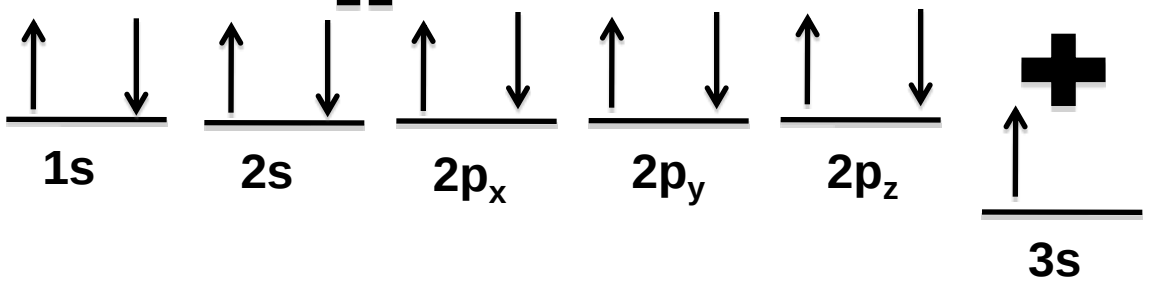
- Let's go through some examples …

- A convenient way to simplify notation:

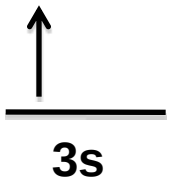
Na $1s^2 2s^2 2p^6 3s^1$



Ne $1s^2 2s^2 2p^6$ ✚ $3s^1$



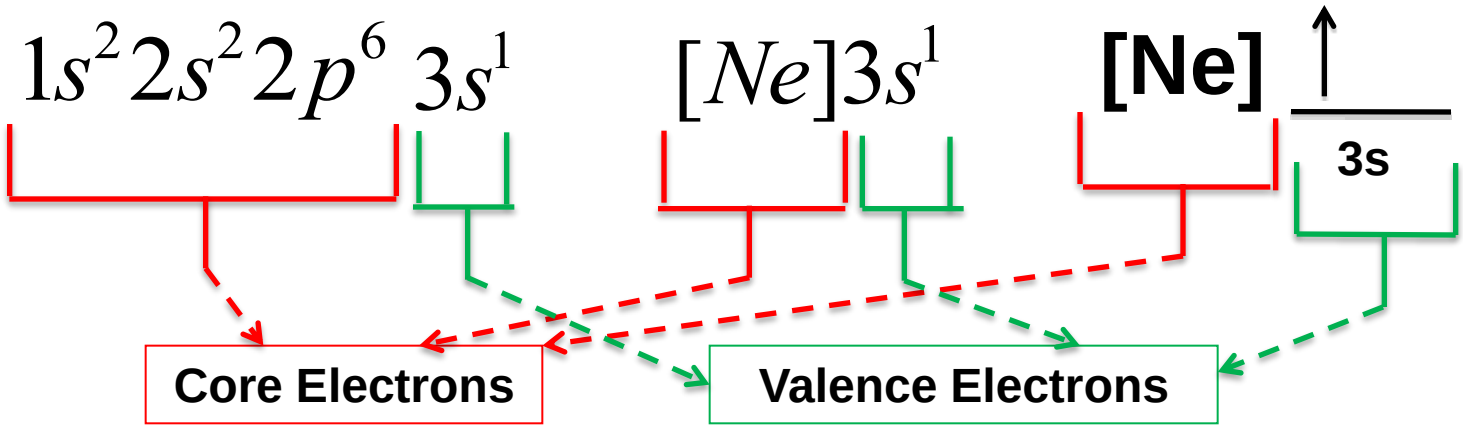
Na $[Ne]3s^1$ **[Ne]**



Core vs. Valence Electrons

- We call the **noble gas** electrons **core** electrons
- We call the **non-noble gas** electrons **valence** electrons
- **Valence electrons** determine most of **chemical properties** of an element

Na $1s^2 2s^2 2p^6 3s^1$ $[Ne]3s^1$ **[Ne]** ↑ 3s



What are the valence electrons in the following atoms?

C **As** **He**

Aufbau Process

- Aufbau = ‘building up’ in German
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- Let’s go through some examples …

Na — *Element*

$[Ne]3s^1$ — *Electron Configuration*

[Ne] ↑ ___ — **3s** — *Orbital Diagram*

- Into what orbital do we put the next electron?

- On your paper, write the electron configurations and orbital diagrams for Mg, Al, Si, P, S, Cl, and Ar

Aufbau Process

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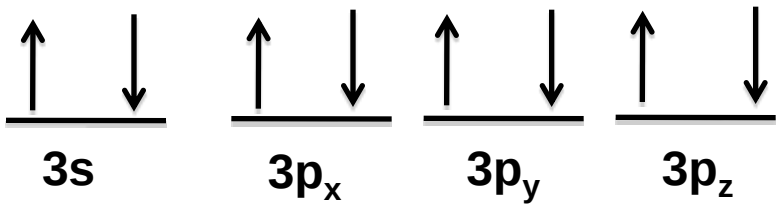
Ar $[Ne]3s^2 3p^6$ **[Ne]**



- Into what orbital do we put the next two electrons?

- Into what shell and sub-shell do we put the third electron?

- How many orbitals are in that sub-shell?

Aufbau Process

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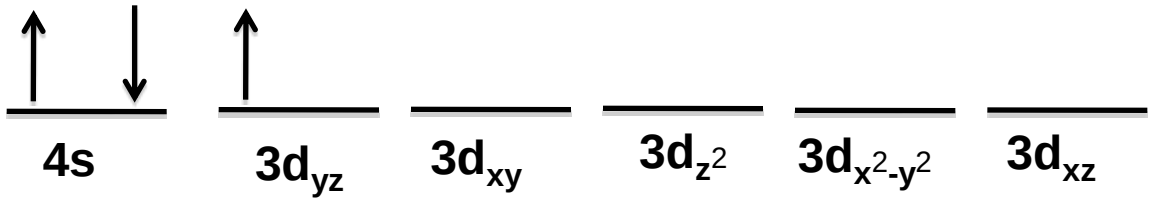
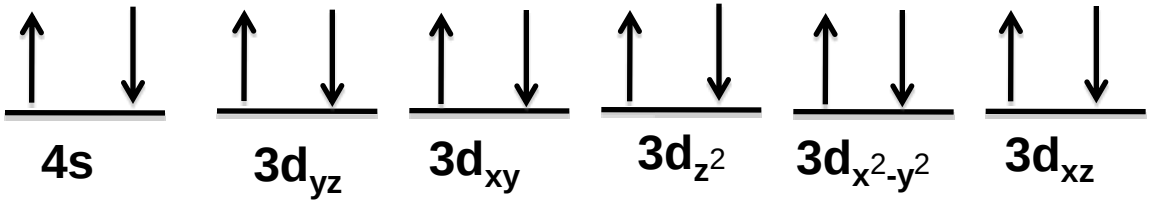
- Describes the way in which the ground state electron configurations of different atoms are built
- Let’s go through some examples …

Sc $[Ar]4s^2 3d^1$ **[Ar]**



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

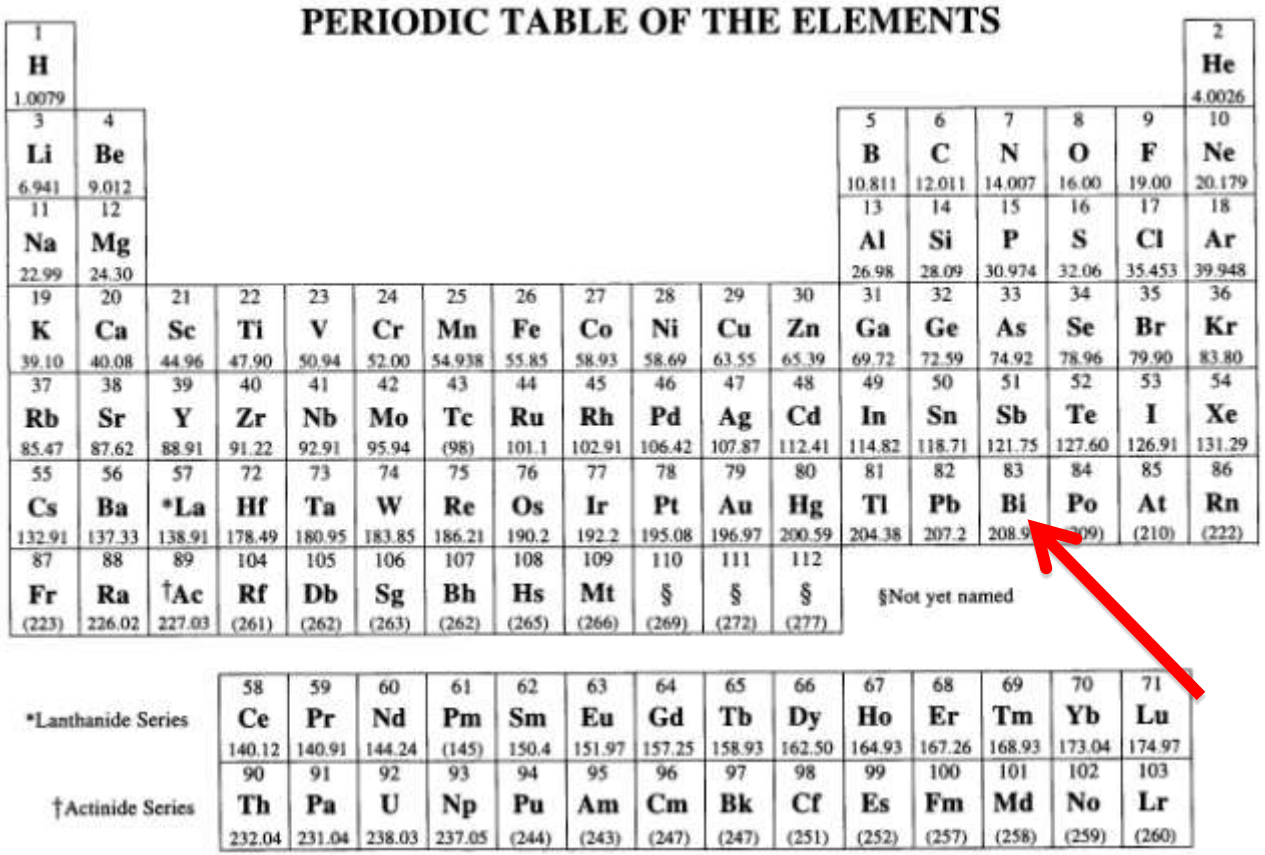


- It looks like we’ve got the idea now …

- … but there are a few exceptions and one helpful trick.

Aufbau Process

- You can use the periodic table to help you write electron configurations



PERIODIC TABLE OF THE ELEMENTS

1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 16.00	9 F 19.00	10 Ne 20.179
11 Na 22.99	12 Mg 24.30											13 Al 26.98	14 Si 28.09	15 P 30.974	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.938	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	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 126.91	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 *La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.2	77 Ir 192.2	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.9	84 Po [illegible]	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.02	89 †Ac 227.03	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 § (269)	111 § (272)	112 § (277)						

§Not yet named

*Lanthanide Series	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	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
†Actinide Series	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	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 (260)

- Let's try writing the electron configuration of Bismuth (Bi)

Aufbau Process

- First, identify the most recently filled noble gas.

PERIODIC TABLE OF THE ELEMENTS

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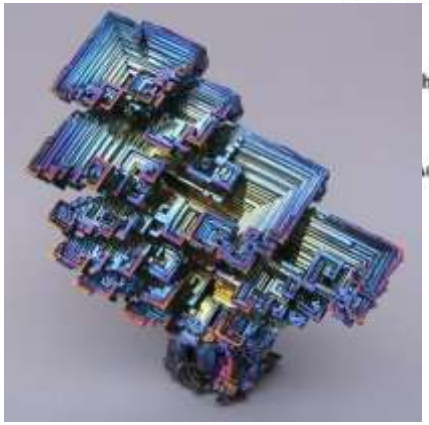
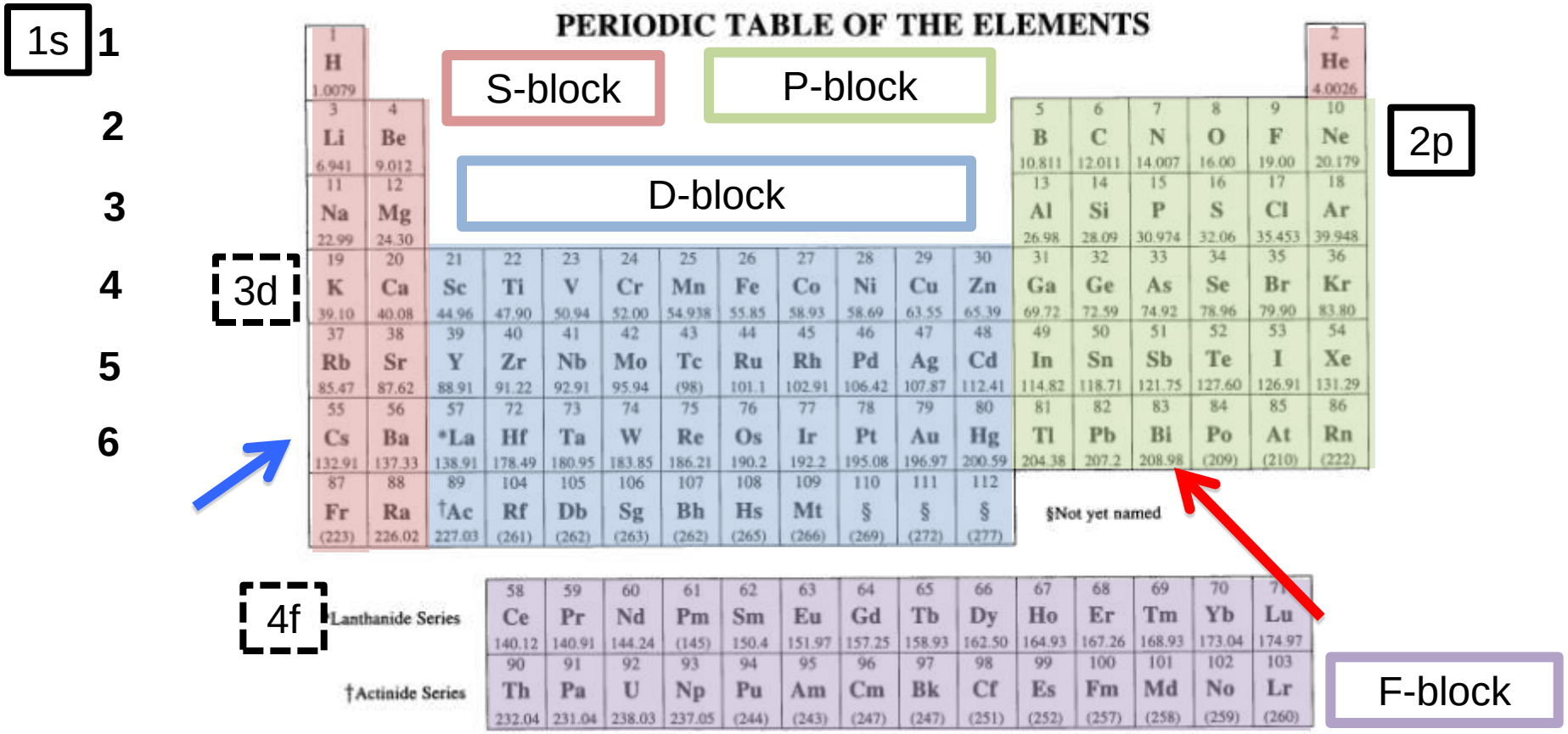


Bi $[Xe]$

Aufbau Process

- Use ‘blocks’ to determine the next sub-shell to fill after the noble gas
- The row (period) tells you the principle quantum number (n)



Bi $[Xe]6s$

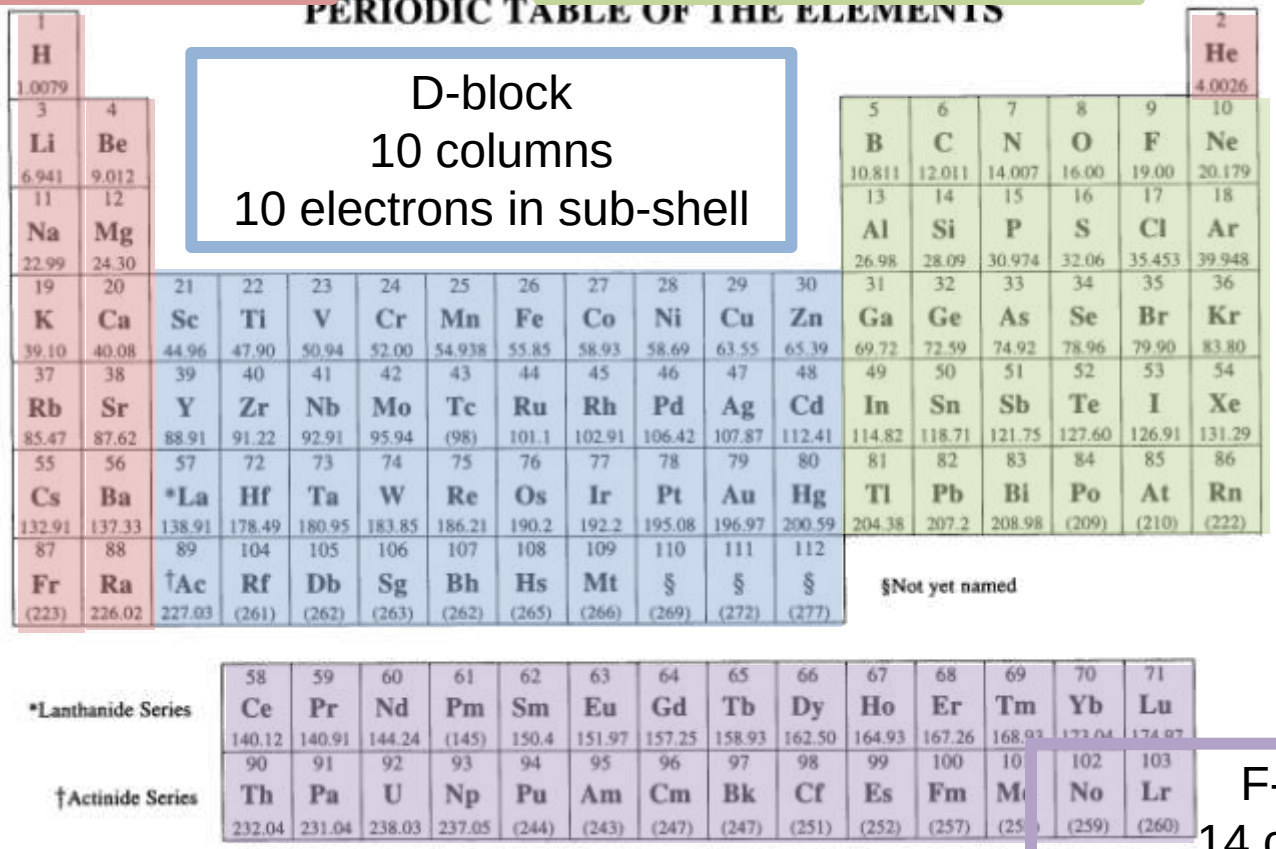
Aufbau Process

- Number of columns in block tells you number of electrons in sub-shell

S-block
2 columns
2 electrons in sub-shell

P-block
6 columns
6 electrons in sub-shell

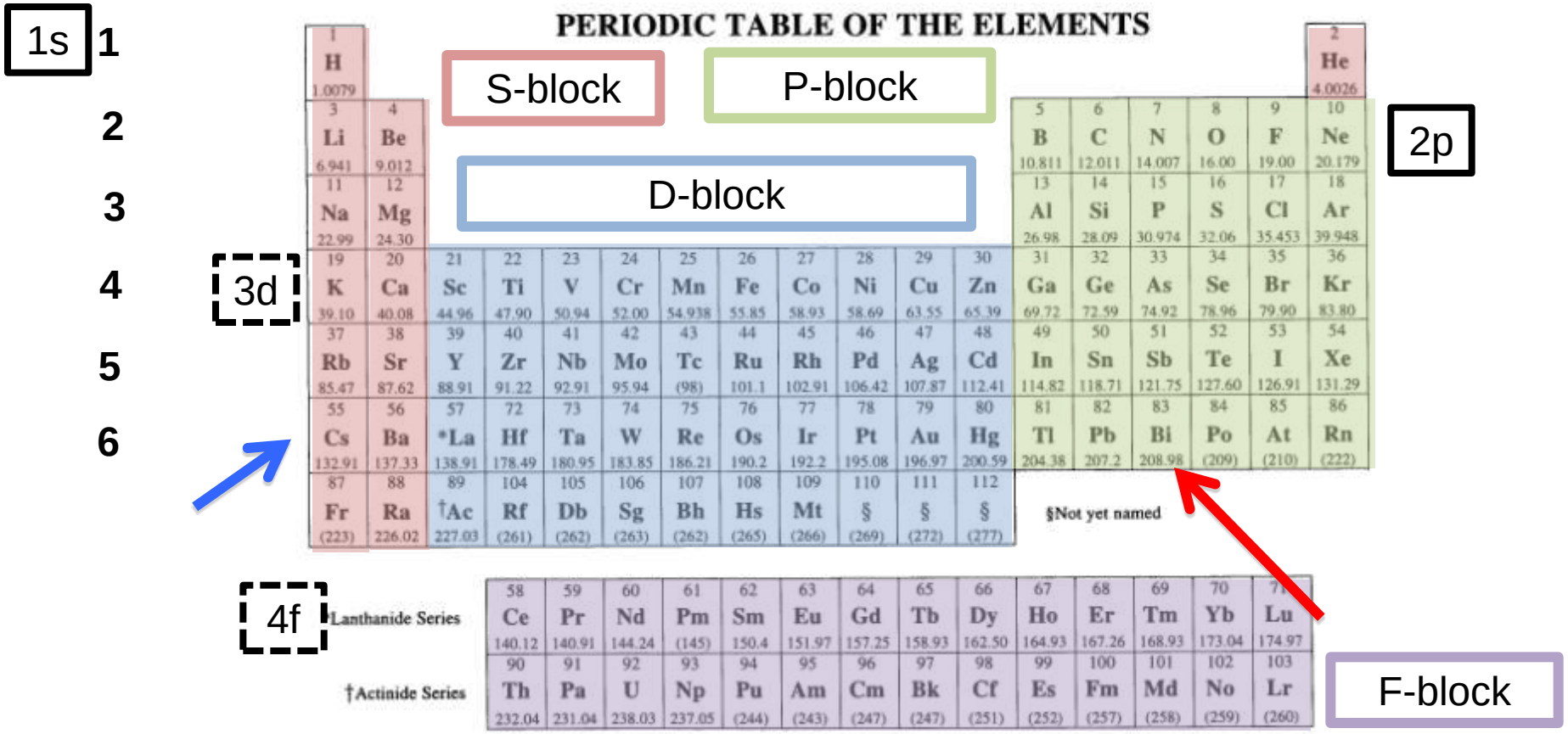
D-block
10 columns
10 electrons in sub-shell



F-block
14 columns
14 electrons in sub-shell

Aufbau Process

- Fill in remaining electrons, working left to right across the table

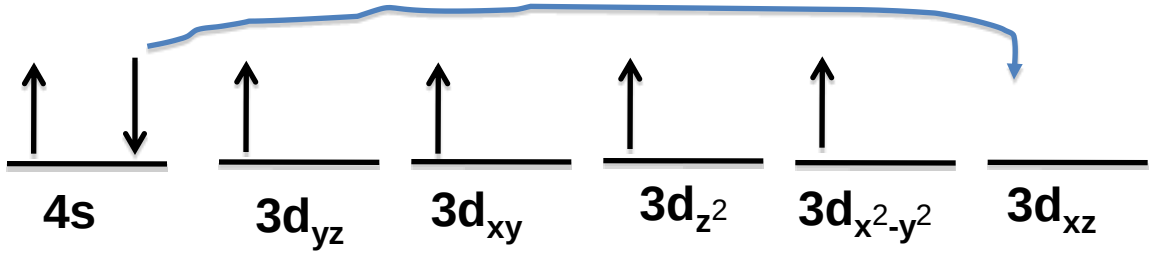


Bi $[Xe]6s^2 4f^{14} 5d^{10} 6p^3$

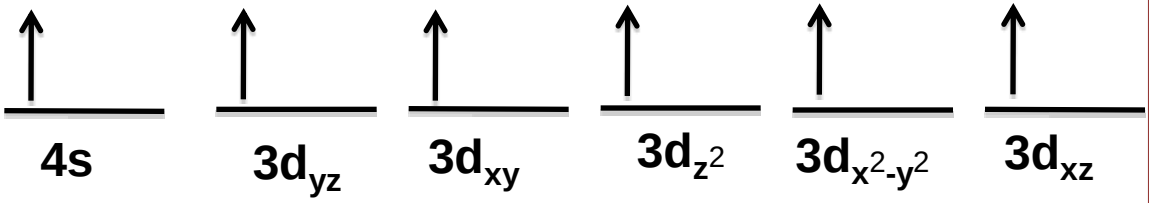
Aufbau Process

- Exceptions: overall energy is sometimes minimized by moving one electron into a higher-energy orbital if that results in a perfectly half-filled or fully filled sub-shell

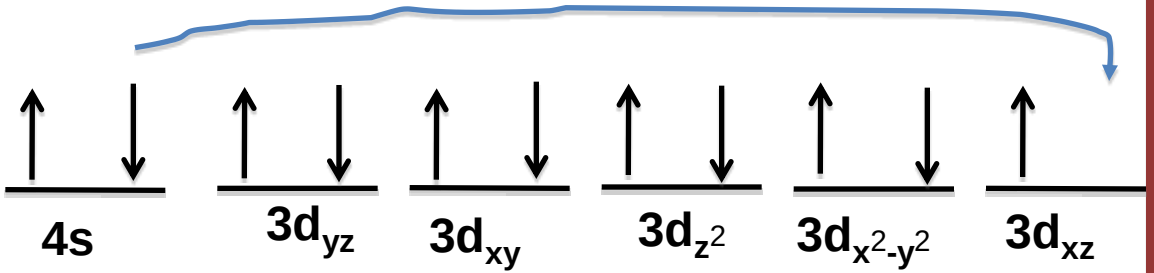
✗ **Cr** $[Ar]4s^2 3d^4$ **[Ar]**



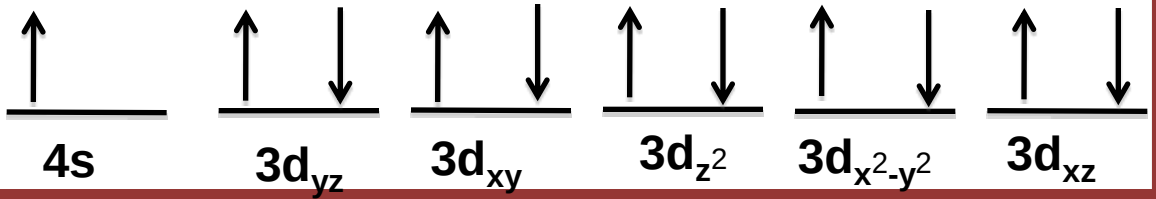
✓ **Cr** $[Ar]4s^1 3d^5$ **[Ar]**



✗ **Cu** $[Ar]4s^2 3d^9$ **[Ar]**



✓ **Cu** $[Ar]4s^1 3d^{10}$ **[Ar]**



Outline

- Electron Configuration (Neutral Atoms)
- Electron Configuration (Ions)

- Electron Configuration (Neutral Atoms)
  - Energy Ordering
  - Pauli Exclusion Principle
  - Hund's Rule
  - Aufbau Process
- Electron Configuration (Ions)
  - Adding Electrons (Making Anions)
  - Removing Electrons (Making Cations)

Adding Electrons

- To make anions, add extra electrons following the Aufbau process for neutral atoms
- Important difference: the total number of electrons will exceed the total number of protons – the atom will be charged

F $[He]2s^2 2p^5$

+ 1 e-

$_7F^-$ $[He]2s^2 2p^6$ $\qquad$ $_8Ne$ $[He]2s^2 2p^6$

Same Number of Electrons
7 Protons vs 8 Protons
Negatively Charged vs Neutral

Atoms with the same number of electrons are **isoelectronic**

Outline

- Electron Configuration (Neutral Atoms)
- Electron Configuration (Ions)

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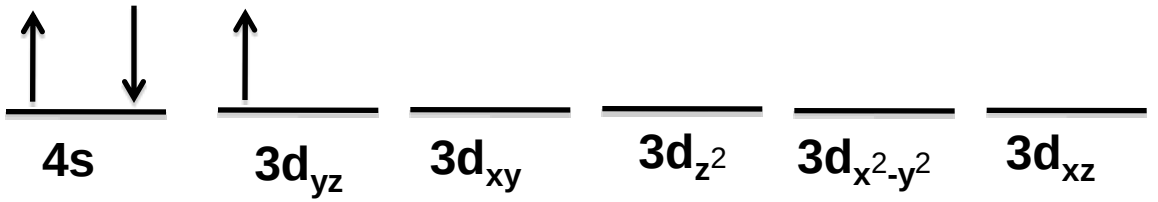
  - Removing Electrons (Making Cations)

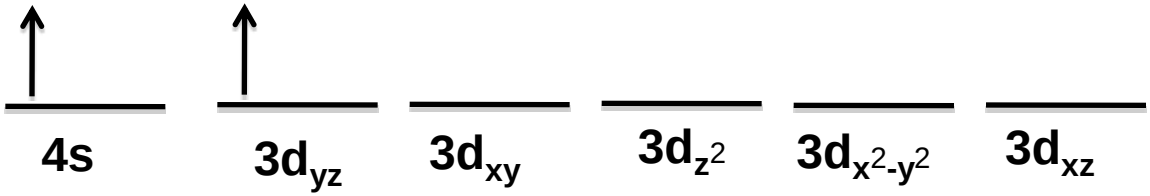
Removing Electrons

- To make cations, remove an electron from the orbital with the highest principal quantum number (n)

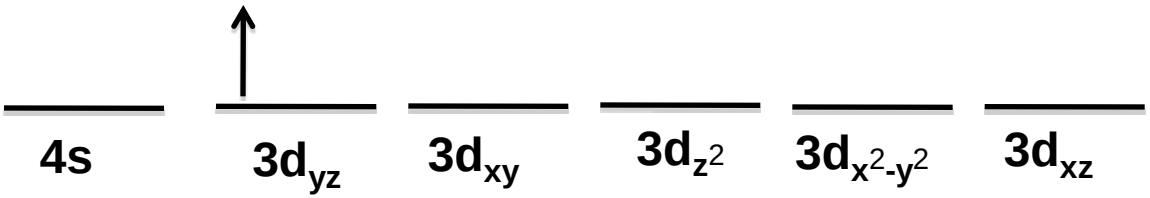
Sc $[Ar]4s^2 3d^1$ **[Ar]**



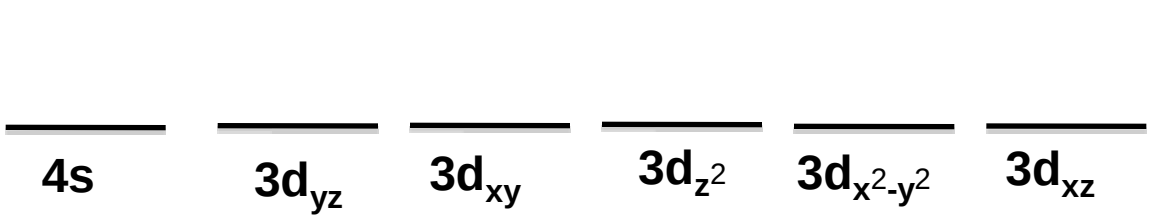
Sc$^+$ $[Ar]4s^1 3d^1$ **[Ar]**



Sc^{2+} $[Ar]3d^1$ **[Ar]**



Sc^{3+} $[Ar]$ **[Ar]**



Summary

- Specific rules govern how electrons fill orbitals in neutral atoms
- For anions, add electrons following the Aufbau process
- For cations, remove electrons from the highest-n orbital

- Next class, we will see how the properties of different atoms follow patterns in their electron configurations

Homework

- Electrons in Atoms Handout (Due Friday)