

# 3D Schrödinger Eq.

Today:

Continue with hydrogen.

Multi-electron atoms

HWK 13 available online.

Please fill out the online participation survey. Worth  
10points on HWK 13.

Final Exam is Monday, Dec. 15 10:30A-1P HERE  
Duane G1B20

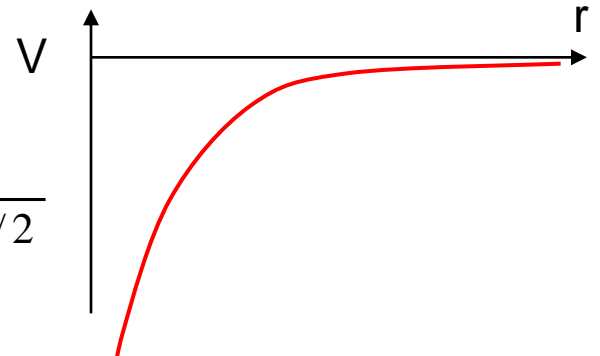
# What is Schrodinger Model of Hydrogen Atom?

Electron is cloud of probability whose wave function  $\Psi(x,t)$  is the solution to the Schrodinger equation:

$$-\frac{\hbar^2}{2m} \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right) \Psi(x, y, z, t) + V(x, y, z) \Psi(x, y, z, t) = i\hbar \frac{\partial}{\partial t} \Psi(x, y, z, t)$$

where:

$$V(x, y, z) = -\frac{Zke^2}{r} = -\frac{Zke^2}{(x^2 + y^2 + z^2)^{1/2}}$$



Can get rid of time dependence and simplify:

Equation in 3D, looking for  $\Psi(x,y,z,t)$ :

$$-\frac{\hbar^2}{2m} \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right) \Psi(x, y, z, t) + V(x, y, z) \Psi(x, y, z, t) = i\hbar \frac{\partial}{\partial t} \Psi(x, y, z, t)$$

Since  $V(x,y,z)$  not function of time:

$$\Psi(x, y, z, t) = \psi(x, y, z) e^{-iEt/\hbar}$$
$$E \psi(x, y, z) e^{-iEt/\hbar}$$

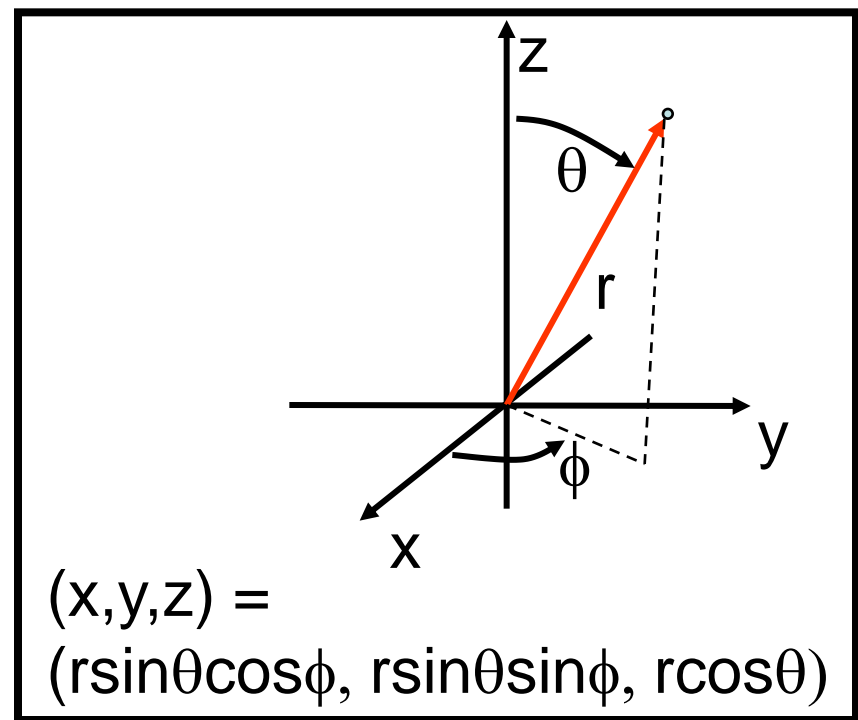
Time independent Schrödinger Equation:

$$-\frac{\hbar^2}{2m} \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right) \psi(x, y, z) + V(x, y, z) \psi(x, y, z) = E \psi(x, y, z)$$

Since potential spherically symmetric “easier” to solve w/ spherical crds:  $(V(r) = -Zke^2 / r)$

Schrödinger’s Equation in Spherical Coordinates & no time:

$$-\frac{\hbar^2}{2m} \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial \psi}{\partial r} \right) - \frac{\hbar^2}{2mr^2} \left[ \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial \psi}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2 \psi}{\partial \phi^2} \right] + V(r)\psi = E\psi$$



Technique for solving = “Separation of Variables”

$$\psi(r, \theta, \phi) = R(r) f(\theta) g(\phi)$$

$$\Psi(r, \theta, \phi, t) = R(r) f(\theta) g(\phi) \underline{e^{-iEt/\hbar}}$$

Have you seen this technique for solving different equations?

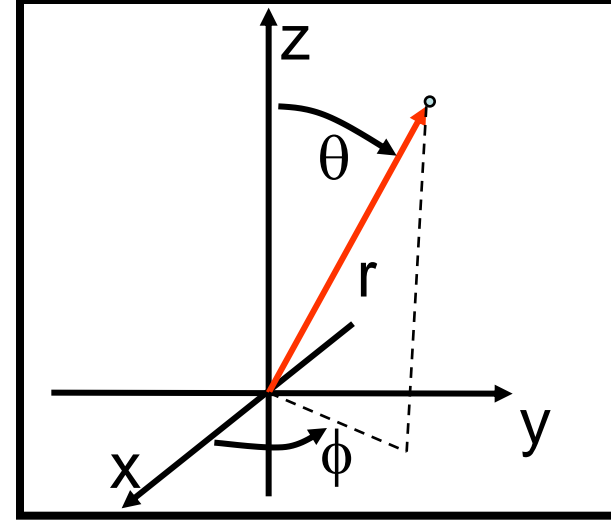
A. yes B. no

In 1D (electron in a wire):

we got quantization from applying boundary conditions in terms of  $x$ .

In 3D, now have **3** degrees of freedom:

Boundary conditions in terms of  $r, \theta, \phi$



What are the boundary conditions on the wavefunction ( $\psi$ ) in  $r$  ?

- a.  $\psi$  must go to 0 at  $r=0$
- b.  $\psi$  must go to 0 at  $r=\text{infinity}$
- c.  $\psi$  at infinity must equal  $\psi$  at 0
- d. A and B
- e. A, B, and C

$\psi$  must be normalizable, so needs to go to zero ...

Also physically makes sense ... not probable to find electron there

In 1D (electron in a wire):

Have 1 quantum number (n).  
Need to specify value of n to know what state electron is in.

$$\Psi_n(x,t) = \psi_n(x)\phi_n(t) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right) e^{-iE_n t/\hbar}$$

In 3D, now have 3 degrees of freedom:

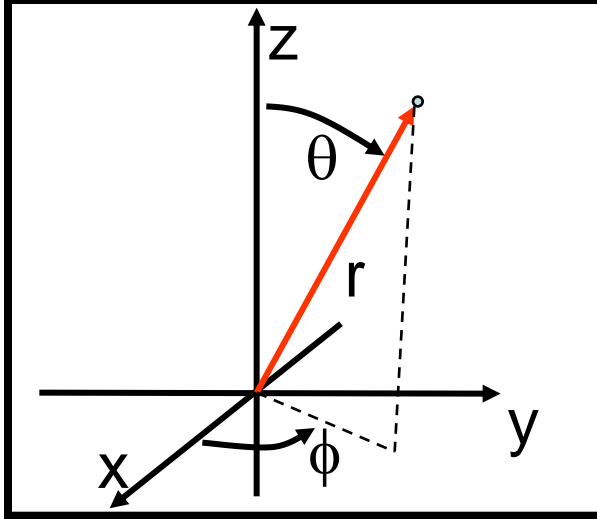
Boundary conditions in terms of r,θ,φ

How many quantum numbers are there in 3D?  
In other words, how many numbers do you need to specify unique wave function? And why? (We'll ask you to explain your reasoning!)

- a. 1
- b. 2
- c. 3
- d. 4
- e. 5

Answer: 3 – Need one quantum number for each dimension:

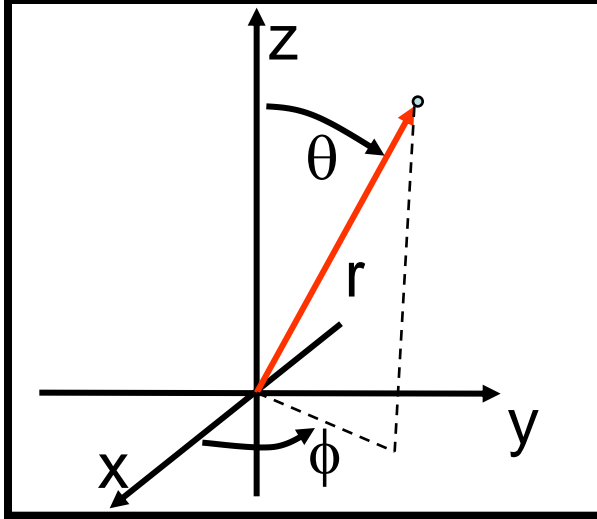
r: n
θ: l
φ: m



(If you said 4 because you were thinking about spin, that's OK too. We'll get to that later.)

In 1D (electron in a wire):  
 Have 1 quantum number (n)

In 3D, now have **3** degrees of freedom:  
 Boundary conditions in terms of r, θ, φ  
 Have 3 quantum numbers (n, l, m)



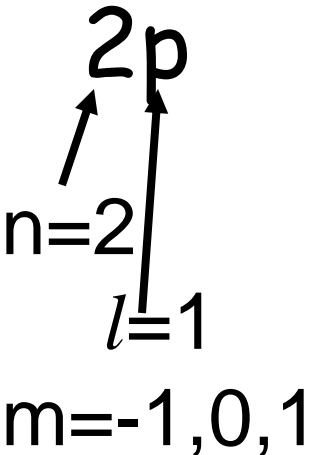
$$\psi_{nlm}(r, \theta, \phi) = R_{nl}(r) f_{lm}(\theta) g_m(\phi)$$

Shape of  $\psi$  depends on n, l, m. Each (nlm) gives unique  $\psi$

n=1, 2, 3 ... = Principle Quantum Number

l=0, 1, 2, 3 ... = Angular Momentum Quantum Number  
 = s, p, d, f (restricted to 0, 1, 2 ... n-1)

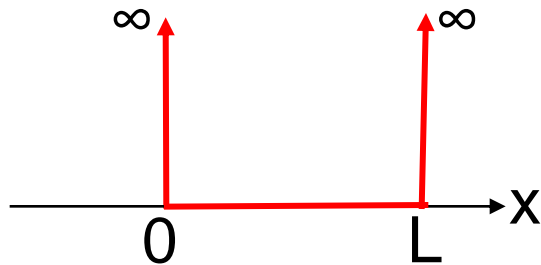
m = ... -1, 0, 1.. = z-component of Angular Momentum  
(restricted to -l to l)



# Comparing H atom & Infinite Square Well:

## Infinite Square Well: (1D)

- $V(x) = 0$  if  $0 < x < L$   
 $\infty$  otherwise



- Energy eigenstates:

$$E_n = \frac{n^2 \pi^2 \hbar^2}{2mL^2}$$

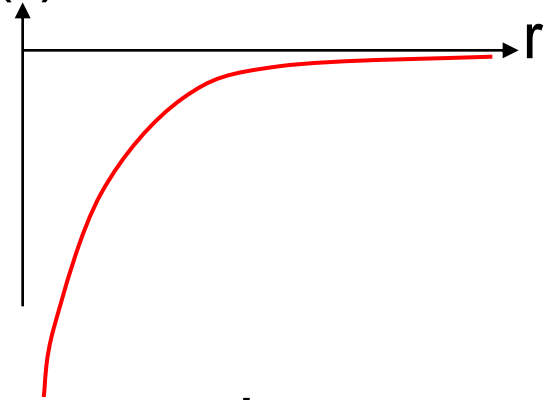
- Wave functions:

$$\psi_n(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right)$$

$$\Psi_n(x, t) = \psi_n(x) e^{-iE_n t / \hbar}$$

## H Atom: (3D)

- $V(r) = -Zke^2/r$



- Energy eigenstates:

$$E_n = -\frac{mZ^2 k^2 e^4}{2\hbar^2 n^2}$$

- Wave functions:

$$\psi_{nlm}(r, \theta, \phi) = R_{nl}(r) f_{lm}(\theta) g_m(\phi)$$

$$\Psi_{nlm}(r, \theta, \phi, t) = \psi_{nlm}(r, \theta, \phi) e^{-iE_n t / \hbar}$$



# What do the wave functions look like?

$$\psi_{nlm}(r, \theta, \phi) = R_{nl}(r) f_{lm}(\theta) g_m(\phi)$$

$n = 1, 2, 3, \dots$

$l$  (restricted to 0, 1, 2 ... n-1)

$m$  (restricted to  $-l$  to  $l$ )

Much harder to draw in 3D than 1D. Indicate amplitude of  $\psi$  with brightness.

1s

Increasing  $n$

Increases distance from nucleus,

Increases # of radial nodes

2s

3s

4s ( $l=0$ )

4p ( $l=1$ )

4d ( $l=2$ )

4f ( $l=3, m=0$ )

Increasing  $l$

Increases angular nodes

Decreases radial nodes

See pictures:  
[www.orbital.com](http://www.orbital.com)

$m=-3$



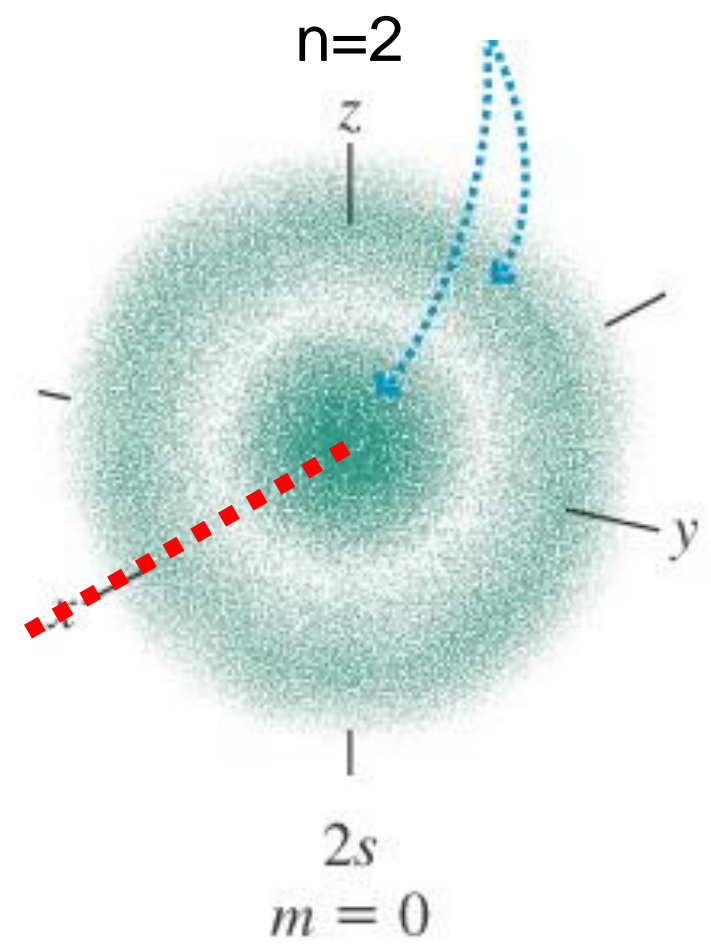
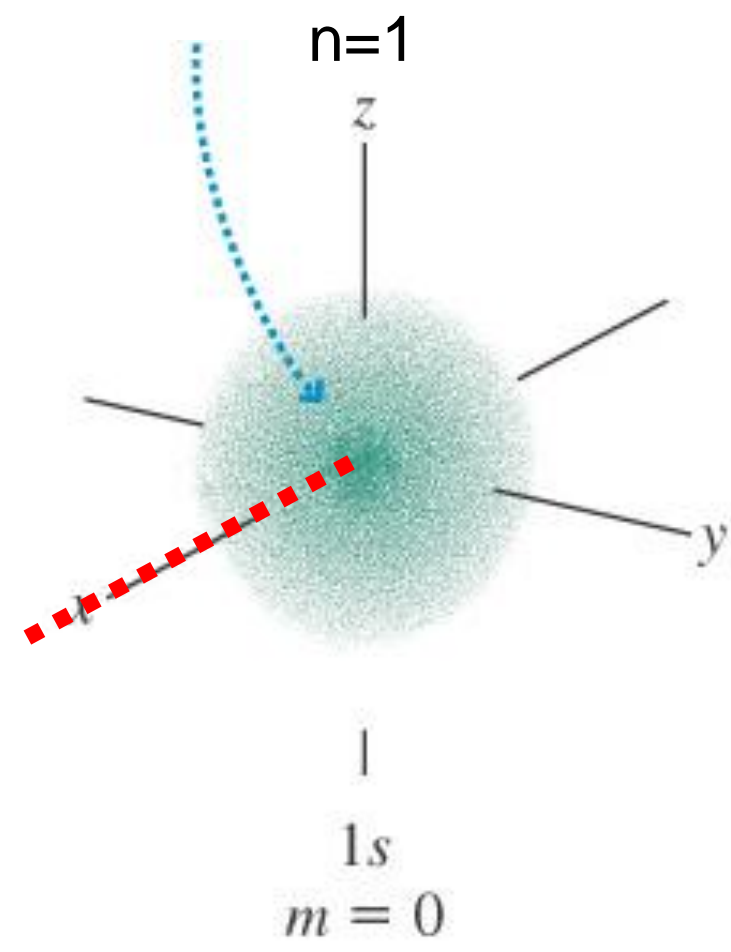
Changes angular distribution

$m=3$

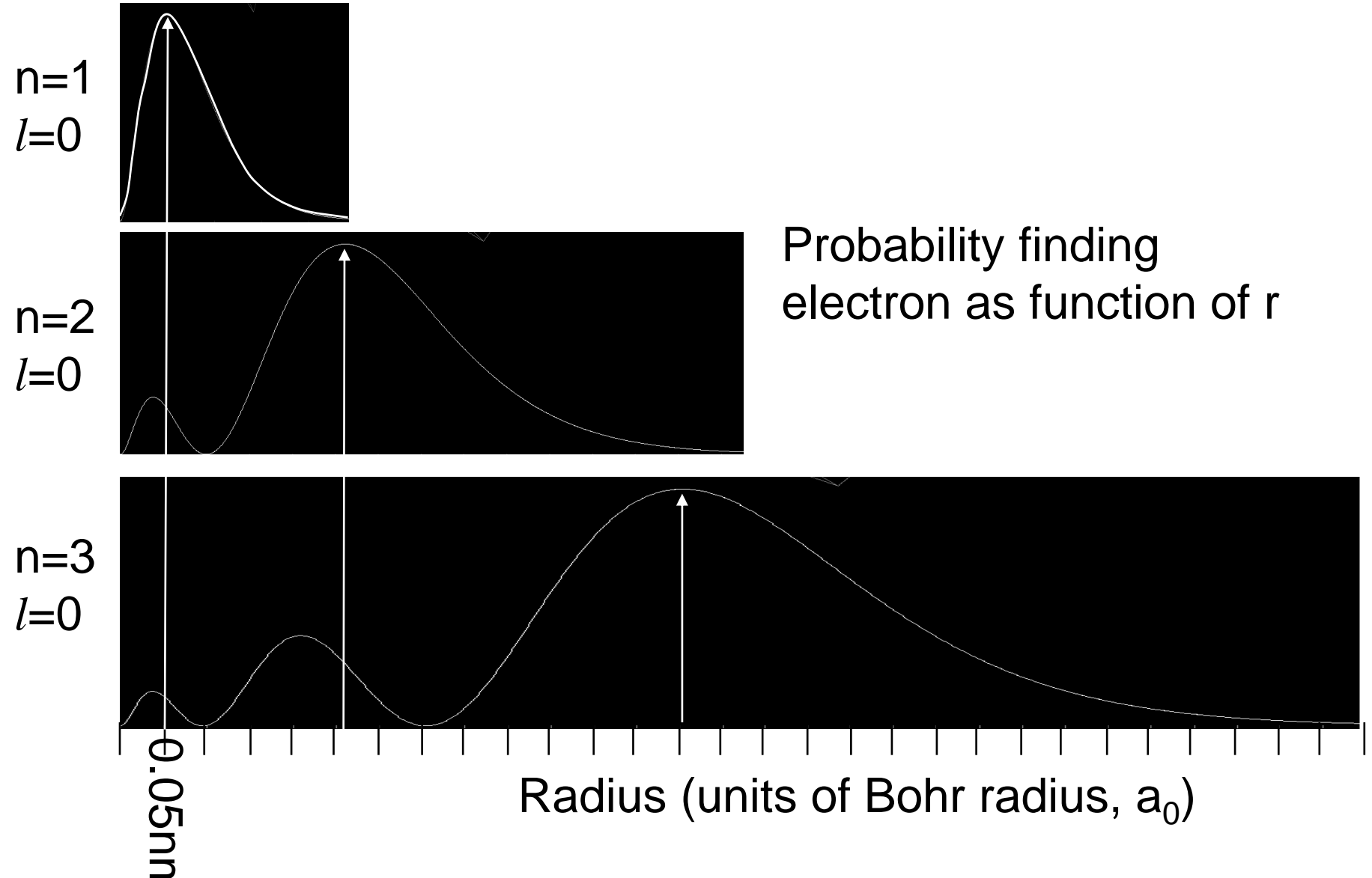
Shapes of hydrogen wave functions:

$$\psi_{nlm}(r, \theta, \phi) = R_{nl}(r) f_{lm}(\theta) g_m(\phi)$$

*Look at s-orbitals ( $l=0$ ): no angular dependence*



Higher  $n \rightarrow$  average  $r$  bigger  
 $\rightarrow$  more spherical shells stacked within each other  
 $\rightarrow$  more nodes as function of  $r$



Shapes of hydrogen wave functions:

$$\psi_{nlm}(r, \theta, \phi) = R_{nl}(r) f_{lm}(\theta) g_m(\phi)$$

$l=1$ , called p-orbitals: angular dependence ( $n=2$ )

$l=1, m=0$ :  $p_z$  = dumbbell shaped.

$l=1, m=-1$ : bagel shaped around z-axis (traveling wave)

$l=1, m=+1$

$$n=2, l=1, m=0 \longrightarrow \psi_{210} = \frac{1}{2\sqrt{6}a_0^3} \frac{r}{a_0} e^{-r/2a_0} \left( -\sqrt{\frac{3}{4\pi}} \cos\theta \right)$$

$$n=2, l=1, m=1 \longrightarrow \psi_{211} = \frac{1}{2\sqrt{6}a_0^3} \frac{r}{a_0} e^{-r/2a_0} \left( -\sqrt{\frac{3}{8\pi}} \sin\theta e^{i\phi} \right)$$

w/time dependence

$$e^{im\phi + iEt/\hbar}$$

Superposition applies:

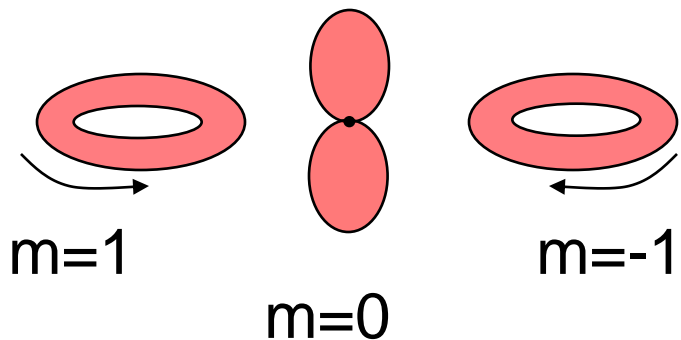
$p_x$  = superposition (addition of  $m=-1$  and  $m=+1$ )

$p_y$  = superposition (subtraction of  $m=-1$  and  $m=+1$ )

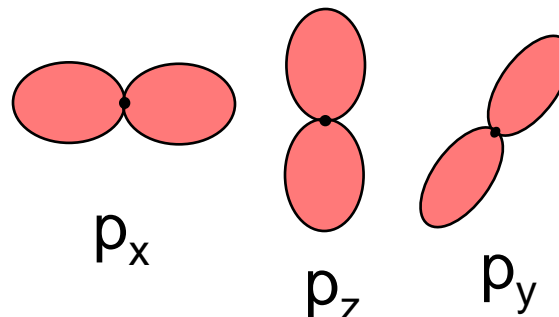
Dumbbells  
(chemistry)

# Physics vs Chemistry view of orbits:

2p wave functions  
(Physics view)  
( $n=2, l=1$ )

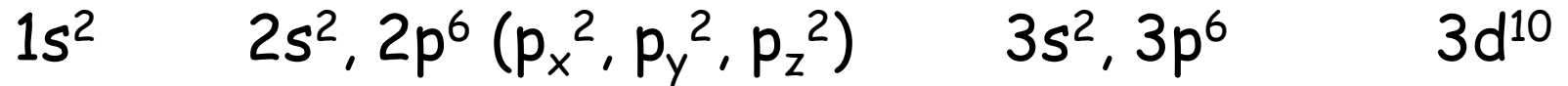


Dumbbell Orbits  
(chemistry)



$p_x$ =superposition  
(addition of  $m=-1$  and  $m=+1$ )  
 $p_y$ =superposition  
(subtraction of  $m=-1$  and  $m=+1$ )

Chemistry: Shells – set of orbitals with similar energy



These are the wave functions (orbitals) we just found:

$n=1, 2, 3 \dots$  = Principle Quantum Number

$$E_n = -E_1 / n^2 \quad (\text{for Hydrogen, same as Bohr})$$

$l=s, p, d, f \dots$  = Angular Momentum Quantum Number  
 $=0, 1, 2, 3$  (restricted to 0, 1, 2 ... n-1)

$$|\vec{L}| = \sqrt{l(l+1)} \hbar$$

$m = \dots -1, 0, 1..$  = z-component of Angular Momentum  
(restricted to -l to l)

$$L_z = m\hbar$$

$n=1, 2, 3 \dots$  = Principle Quantum Number

$$E_n = -E_1 / n^2 \quad (\text{for Hydrogen, same as Bohr})$$

$l=s, p, d, f \dots$  = Angular Momentum Quantum Number

$=0, 1, 2, 3$  (restricted to  $0, 1, 2 \dots n-1$ )

$$|\vec{L}| = \sqrt{l(l+1)} \hbar$$

$m = \dots -1, 0, 1 \dots$  = z-component of Angular Momentum

(restricted to  $-l$  to  $l$ )

$$L_z = m\hbar$$

An electron in hydrogen is excited to Energy =  $-13.6/9$  eV. How many different wave functions  $\psi_{nlm}$  in H have this energy?

[graded indep. but use groups]

- a. 1    b. 3    c. 6    d. 9    e. 10

An electron in hydrogen is excited to Energy =  $-13.6/9$  eV. How many different wave functions in H have this energy?

- a. 1    b. 3    c. 6    d. 9    e. 10

$n =$  Principle Quantum Number:  $E_n = -E_1 / n^2 \longrightarrow n=3$

$l =$  (restricted to 0, 1, 2 ... n-1)  $\longrightarrow l=0,1,2$

$m =$  (restricted to  $-l$  to  $l$ )

<u>n</u>	<u>l</u>	<u>m</u>	
3	0	0	3s states
3	1	-1	
3	1	0	
3	1	1	3p states ( $l=1$ )
3	2	-2	
3	2	-1	
3	2	0	3d states ( $l=2$ )
3	2	1	
3	2	2	
3	2	2	

Answer is d:

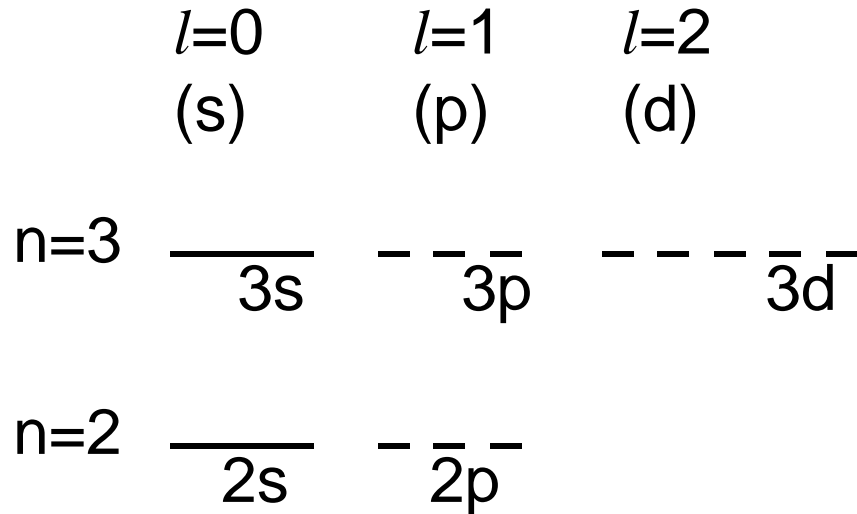
9 states all with the same energy

Isn't this cool...

Chemists had already figured out rules for how many electrons could be in each shell. Didn't know why. Solving Schrödinger equation explains WHY!



# Energy Diagram for Hydrogen



In HYDROGEN, energy only depends on  $n$ , not  $l$  and  $m$ .

(NOT true for multi-electron atoms!)



$n=1, 2, 3 \dots$  = Principle Quantum Number

$$E_n = -E_1 / n^2 \quad (\text{for Hydrogen, same as Bohr})$$

$l=s, p, d, f \dots$  = Angular Momentum Quantum Number  
 $=0, 1, 2, 3$  (restricted to  $0, 1, 2 \dots n-1$ )

$$|\vec{L}| = \sqrt{l(l+1)} \hbar$$

$m = \dots -1, 0, 1 \dots$  = z-component of Angular Momentum  
(restricted to  $-l$  to  $l$ )

$$L_z = m\hbar$$

What is the magnitude of the angular momentum of the ground state of Hydrogen?

- a. 0    b.  $\hbar$     c.  $\sqrt{2}\hbar$     d. not enough information

Answer is a.

$n=1$  so  $l=0$  and  $m=0 \dots$  Angular momentum is 0  $\dots$

Schrodinger finds quantization of energy and angular momentum:

$$n=1, 2, 3 \dots$$

$$l=0, 1, 2, 3 \text{ (restricted to } 0, 1, 2 \dots n-1)$$

$$E_n = -E_1 / n^2$$

$$|\vec{L}| = \sqrt{l(l+1)} \hbar$$

**How does Schrodinger compare to what Bohr thought?**

- I. The energy of the ground state solution is same
- II. The angular momentum of the ground state solution is different
- III. The location of the electron is different

- a. same, same, same
- b. same, same, different
- c. same, different, different
- d. different, same, different
- e. different, different, different

Bohr got energy right, but he said angular momentum  $L=n\hbar$ , and thought the electron was a point particle orbiting around nucleus.

## Solved S's equation for hydrogen:

wave functions, energies, angular momentum

In atom with **multiple electrons**, what do you expect to change in the way you set up the problem?  
and in the solutions?

Student Ideas:

A.

B.

C.

D.

E.

F.

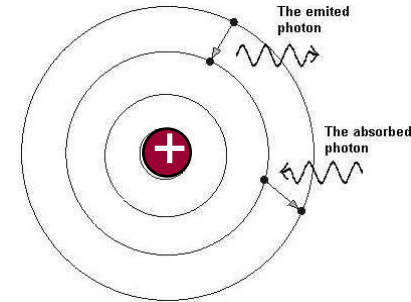
G.

# How does Schrodinger model of atom compare with other models?

## Why is it better?

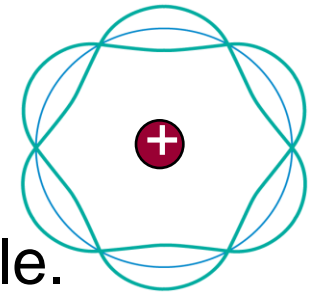
- Bohr model:

- Gives correct energies.
- Postulates fixed energy levels.
- Doesn't explain WHY energy levels fixed.
- Describes electron as point particle moving in circle.



- deBroglie model:

- Also gives correct energies.
- Explains fixed energy levels by postulating electron is standing wave, not orbiting particle.
- Only looks at wave around a ring: basically 1D, not 3D
- Gets angular momentum wrong.
- Can't generalize to multi-electron atoms.

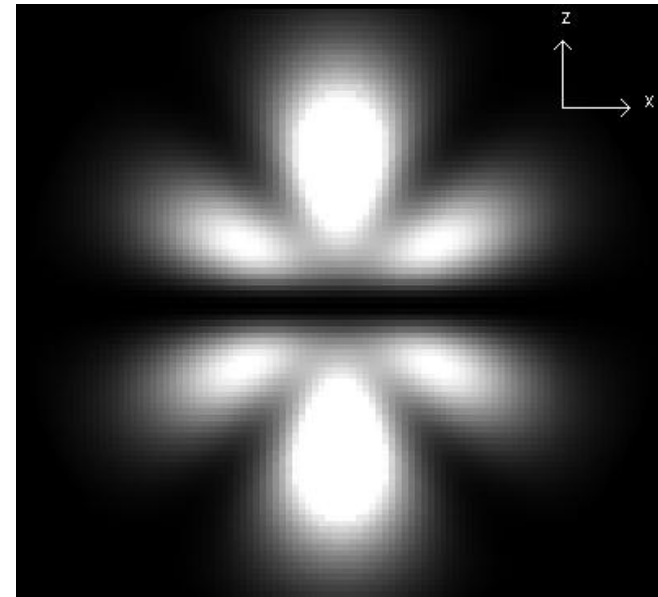


# How does Schrodinger model of atom compare with other models?

## Why is it better?

- Schrodinger model:
  - Gives correct energies.
  - Gives correct angular momentum.
  - Describes electron as 3D wave of probability.
  - Quantized energy levels result from boundary conditions.
  - Schrodinger equation can generalize to multi-electron atoms.

How?



# Why is each model useful?

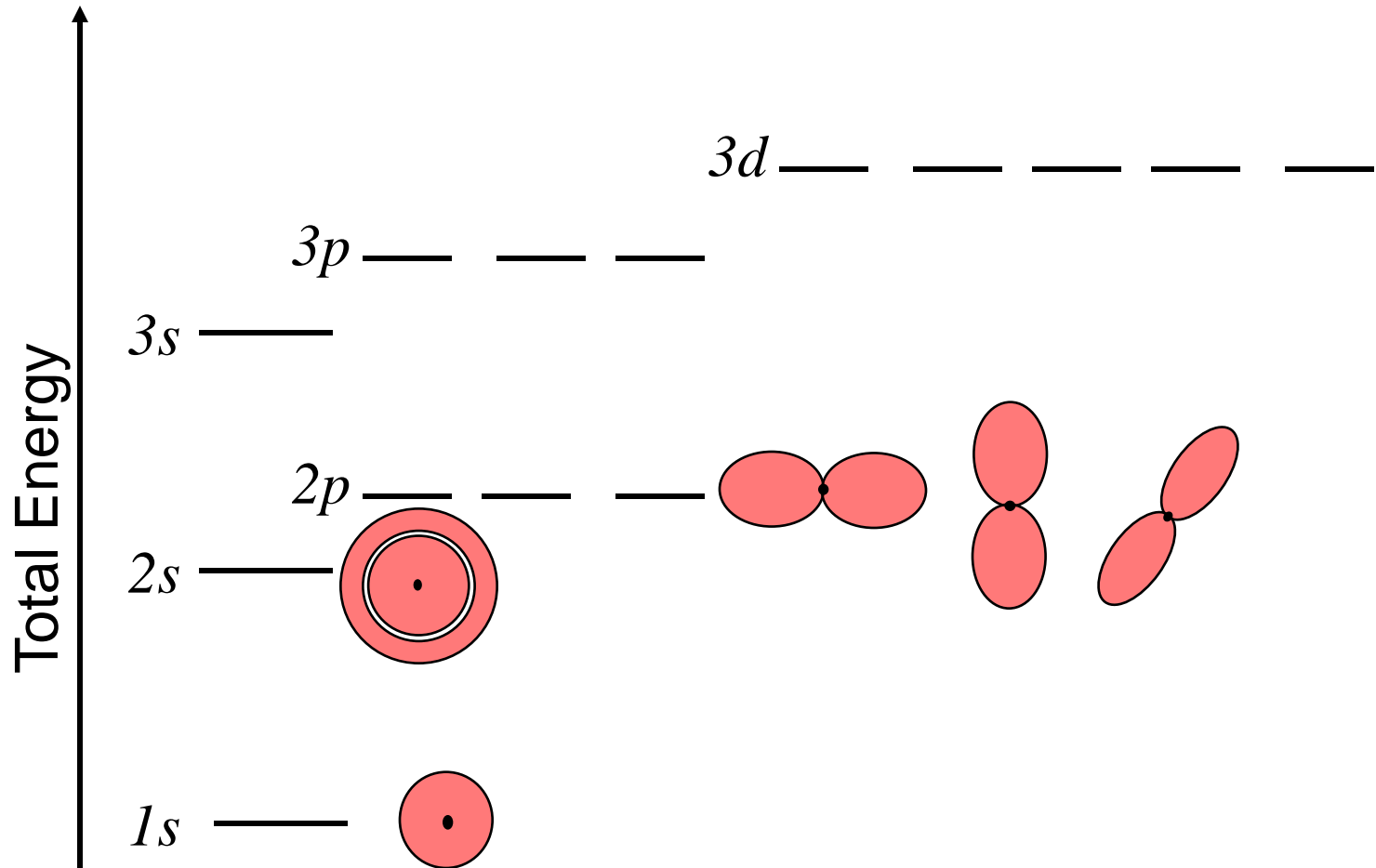
- Bohr – useful for thinking about energy levels, predicting spectral lines.
- deBroglie – useful for giving simple model of how wave properties lead to quantization.
- Schrodinger – useful for describing how atoms interact, shells, chemistry, atoms with more than one electron.

# A brief review of chemistry

Electron configuration in atoms:

How do the electrons fit into the available orbitals?

What are energies of orbitals?





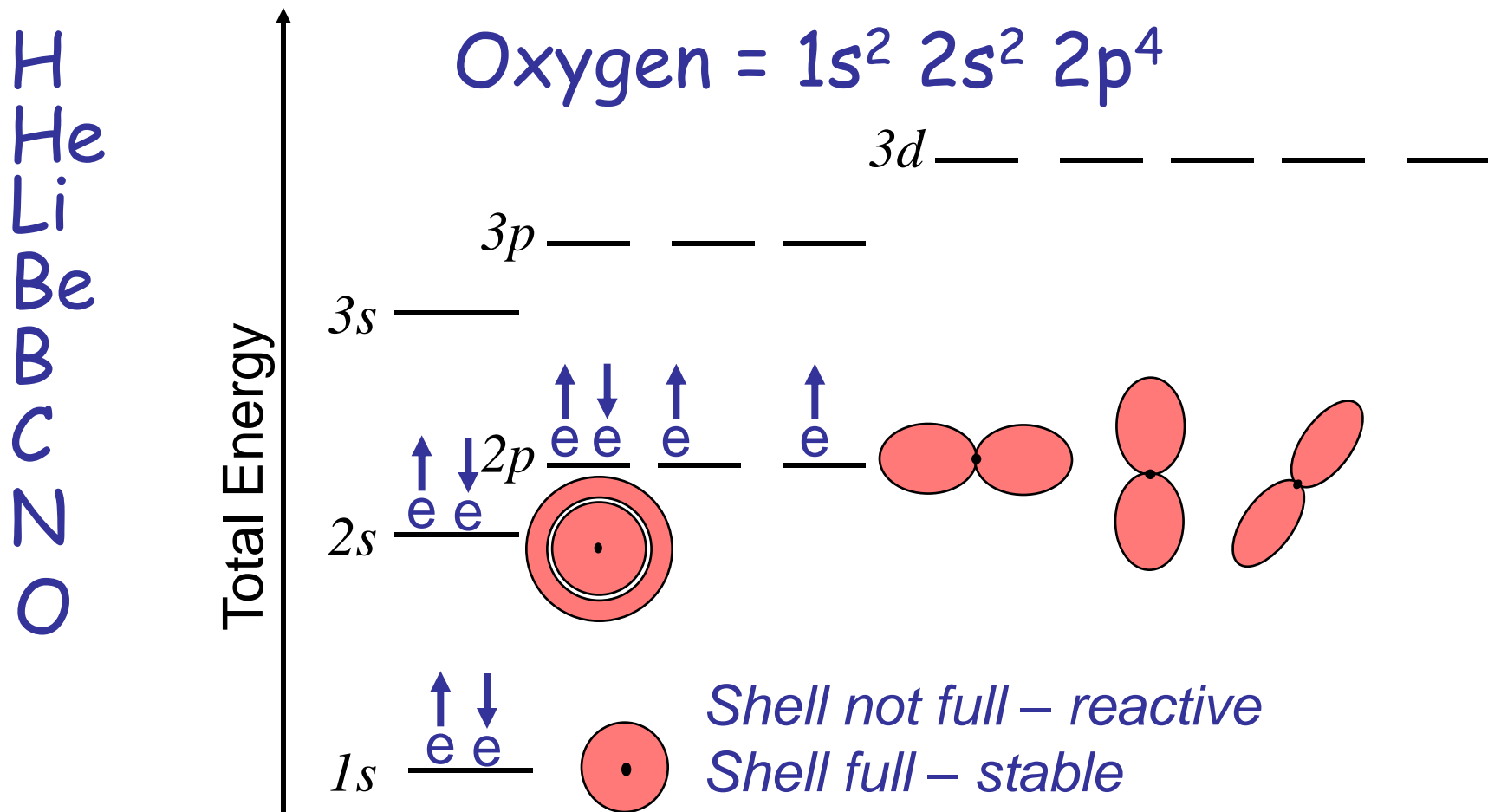
# A brief review of chemistry

Electron configuration in atoms:

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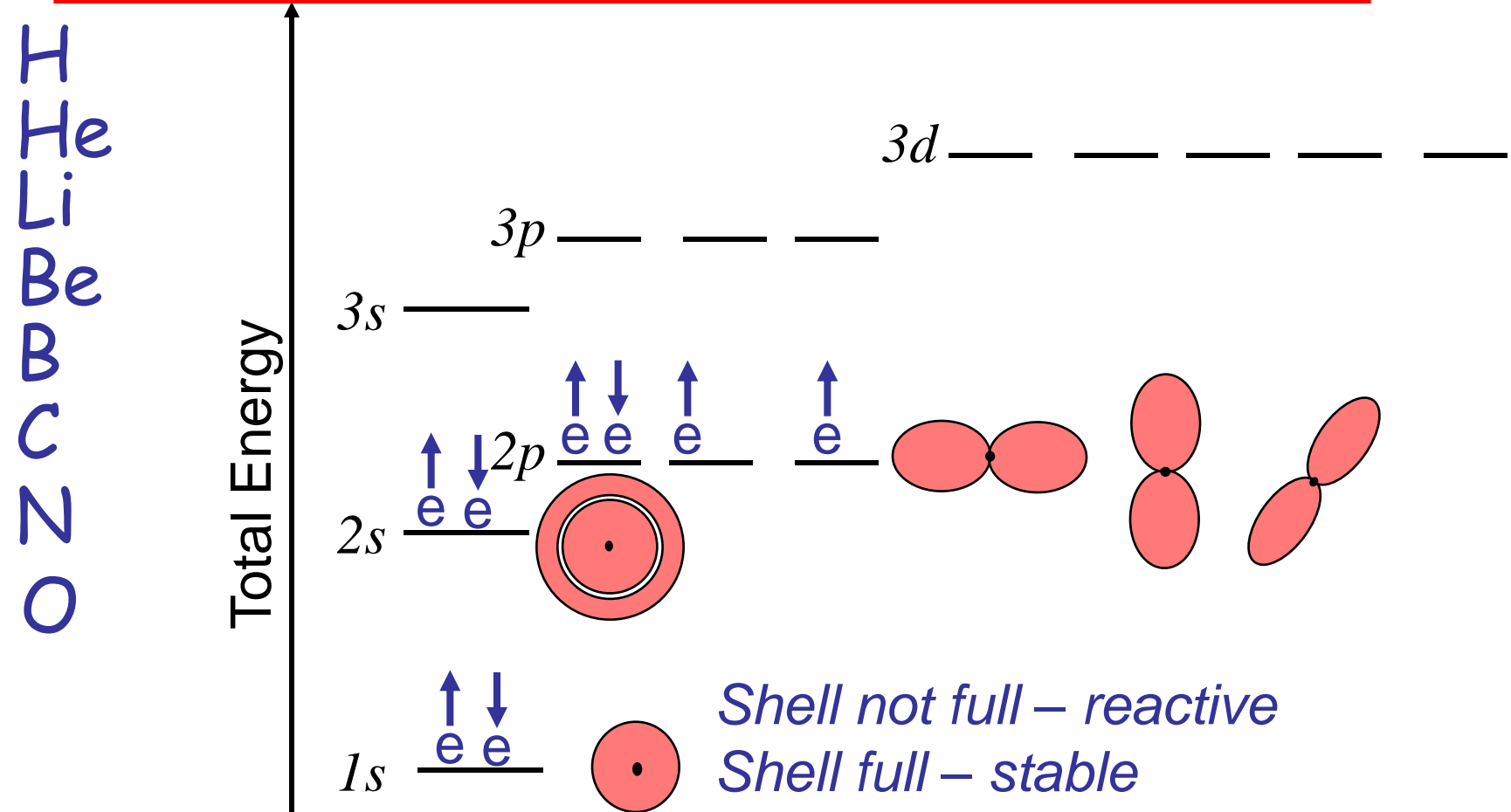
Filling orbitals ... lowest to highest energy, 2 e's per orbital



Will the 1s orbital be at the same energy level for each atom? Why or why not? What would change in Schrodinger's equation?

**No. Change number of protons ... Change potential energy in Schrodinger's equation ... 1s held tighter if more protons.**

**The energy of the orbitals depends on the atom.**



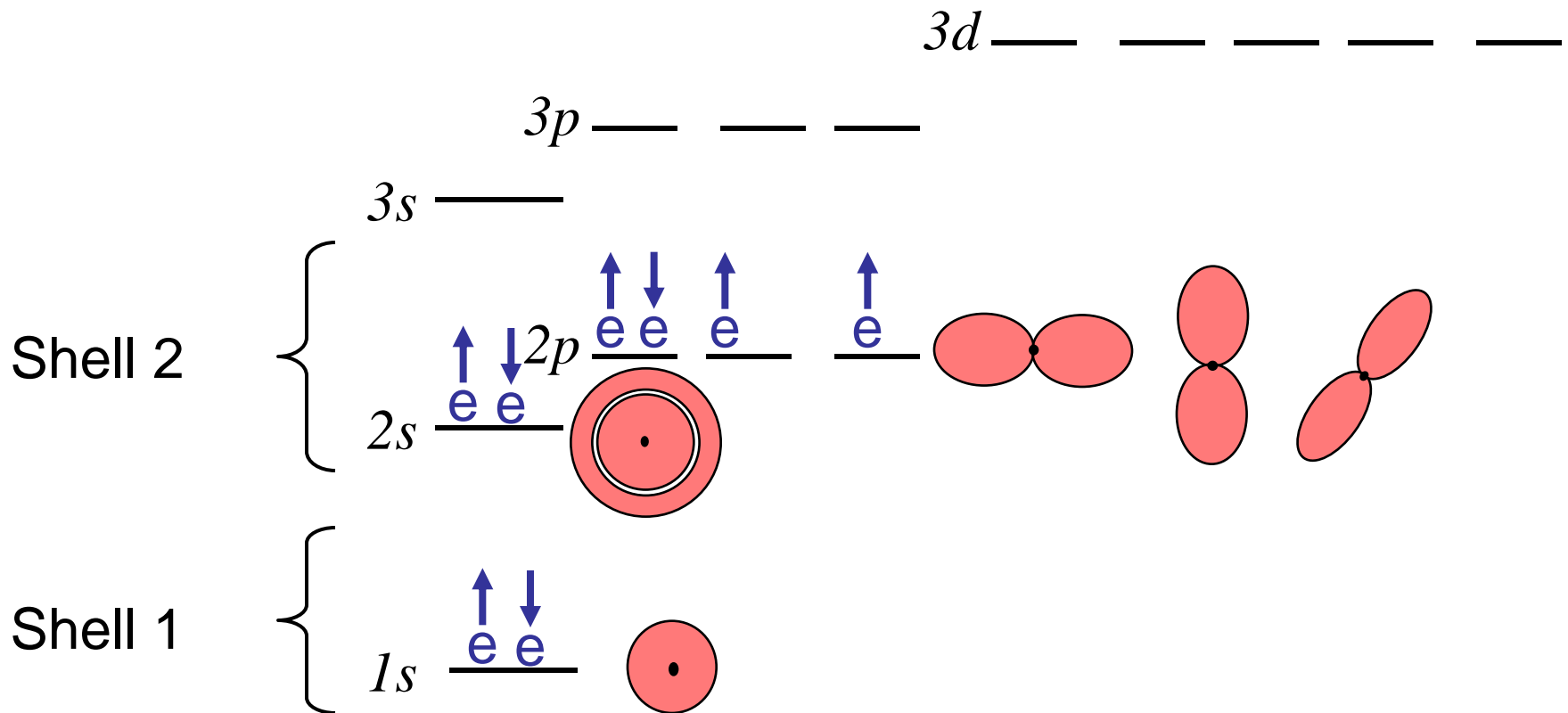
# A brief review of chemistry

Electron configuration in atoms:

How do the electrons fit into the available orbitals?

What are energies of orbitals?

1, 2, 3 ... principle quantum number, tells you *some* about energy  
s, p, d ... tells you *some* about geometric configuration of orbital



# Can Schrodinger make sense of the periodic table?

		Atomic number																																																																																																																																																																																																																																																																																								
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(c)1998  
Kramer Paul

## Schrodinger's solution for multi-electron atoms

Need to account for all the interactions among the electrons

Must solve for all electrons at once! (use matrices)

$$V \text{ (for } q_1) = kq_{\text{nucleus}} * q_1 / r_{n-1} + kq_2 q_1 / r_{2-1} + kq_3 q_1 / r_{3-1} + \dots$$

# Schrodinger's solution for multi-electron atoms

What's different for these cases?

Potential energy (V) changes!

(Now more protons AND other electrons)

$$V \text{ (for } q_1) = kq_{\text{nucleus}}q_1/r_{n-1} + kq_2q_1/r_{2-1} + kq_3q_1/r_{3-1} + \dots$$

Need to account for all the interactions among the electrons

Must solve for all electrons at once! (use matrices)

***Gets very difficult to solve ... huge computer programs!***

Solutions change:

- **wave functions change**

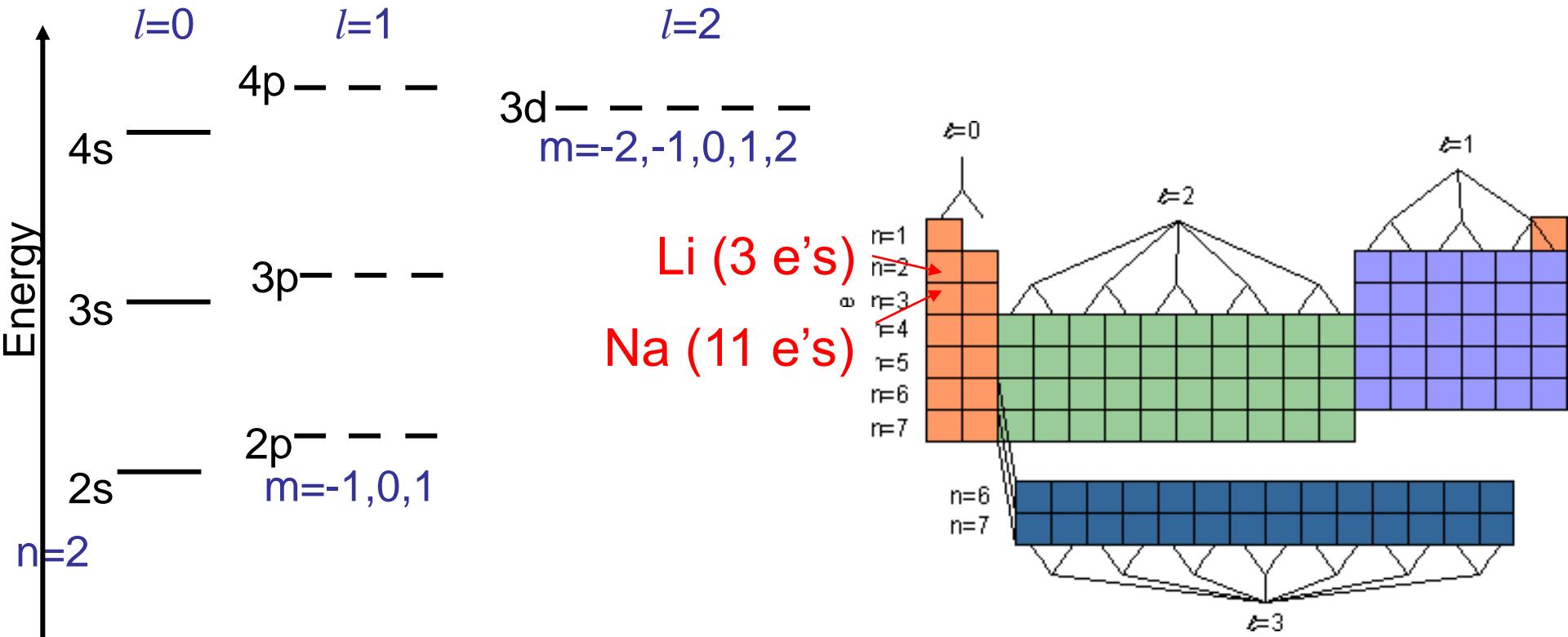
higher  $Z \rightarrow$  more protons  $\rightarrow$  electrons in 1s more strongly bound  $\rightarrow$  radial distribution quite different

general shape (p-orbital, s-orbital) similar but not same

- **energy of wave functions affected by  $Z$  (# of protons)**

higher  $Z \rightarrow$  more protons  $\rightarrow$  electrons in 1s more strongly bound (more negative total energy)

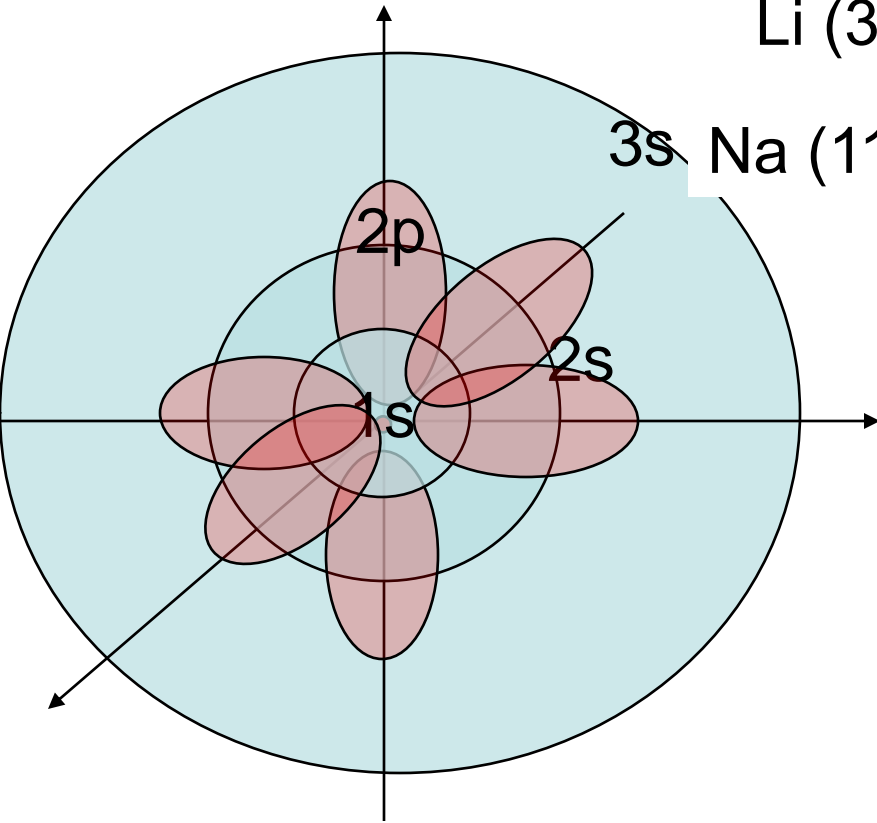
For a given atom, Schrodinger predicts allowed wave functions and energies of these wave functions.



Why would behavior of Li be similar to Na?

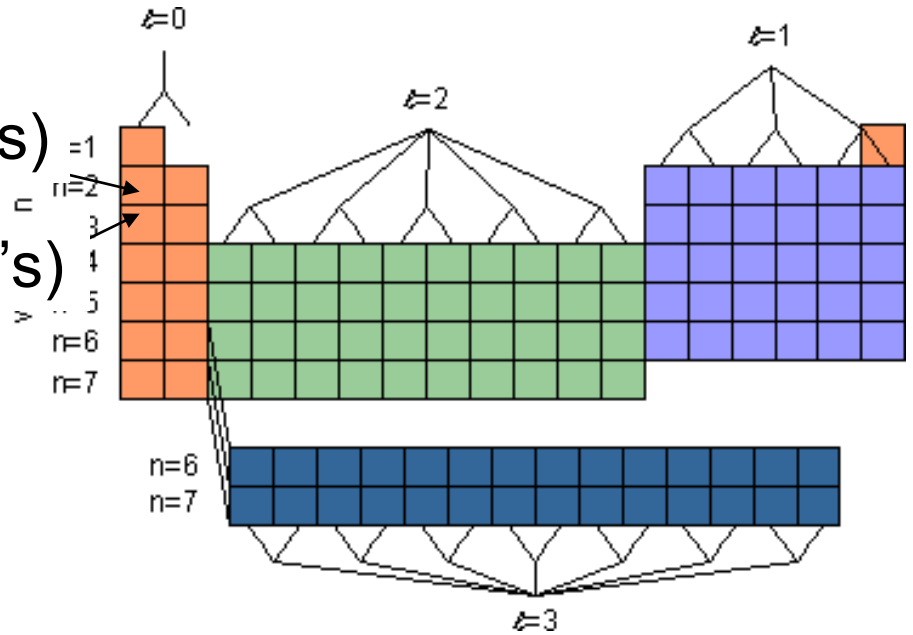
- because shape of outer most electron is similar.
- because energy of outer most electron is similar.
- both a and b
- some other reason

# Wave functions for Li vs Na



Li (3 e's)

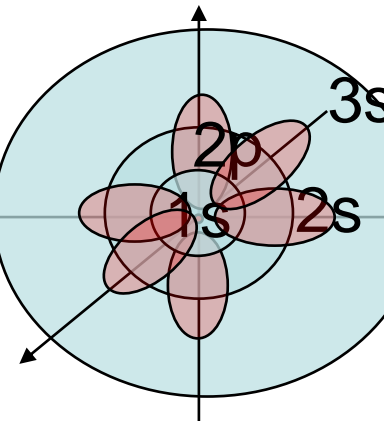
Na (11 e's)



In case of Na, what will energy of outermost electron be and WHY?

- much more negative than for the outermost electron in Li
- similar to the energy of the outermost electron in Li
- much less negative than for the outermost electron in Li

## Wave functions for sodium



### What affects total energy of outermost electron?

1. The effective charge (force) it feels towards center of atom.
2. It's distance from the nucleus.

### What effective charge does 3s electron feel pulling it towards the nucleus?

Close to 1 proton... 10 electrons closer in **shield** (cancel) a lot of the nuclear charge.

### What about distance?

**In H**, 3s level is on average 9x further than 1s, so  $9 \times$  Bohr radius.

**In Na**, 11 protons pull 1s, 2s, 2p closer to nucleus  
distance of 3s not as far out.

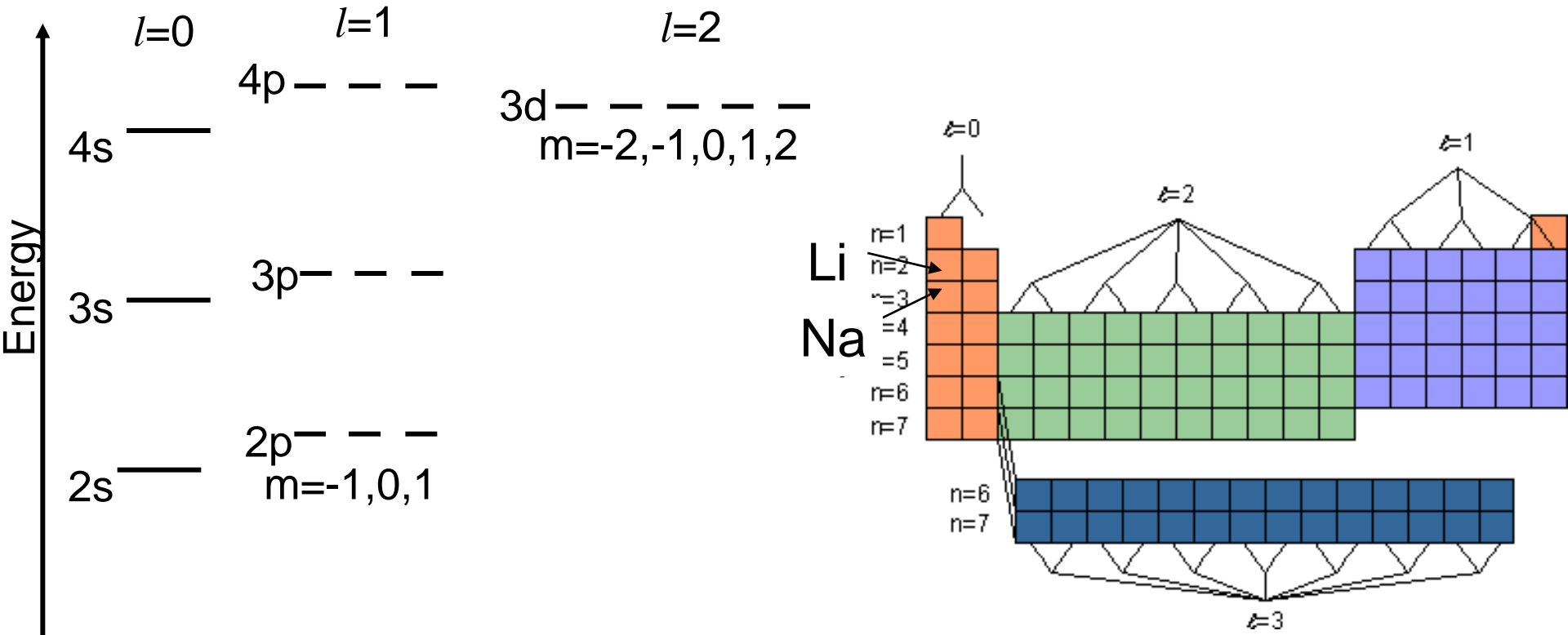
Electron in 3s is a bit further than 1s in H, but ~same as 2s in Li.  
Proximity of electrons in 1s, 2s, 2p is what makes 3s a bit bigger.

In case of Na, what will energy of outermost electron be and WHY?

**b. very** similar to the energy of the outermost electron in Li  
**AND somewhat** (within a factor of 3) of the ground state of H



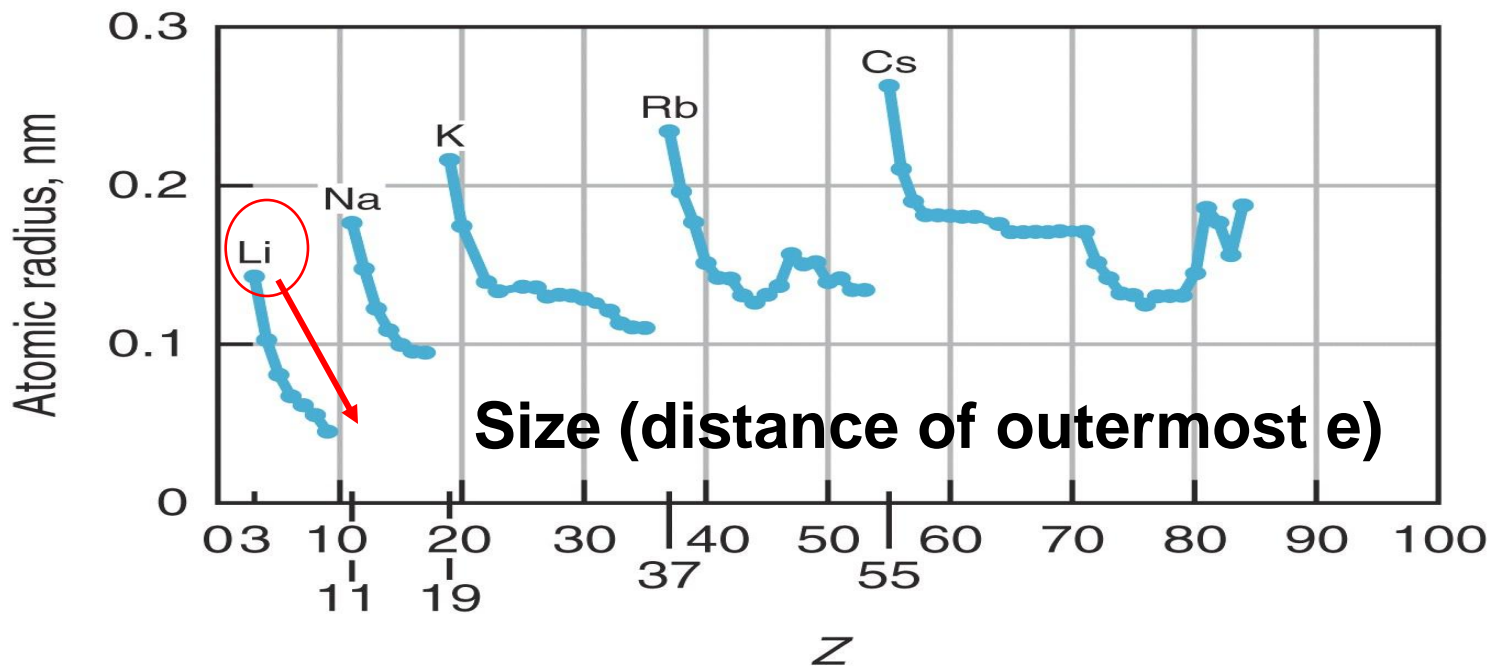
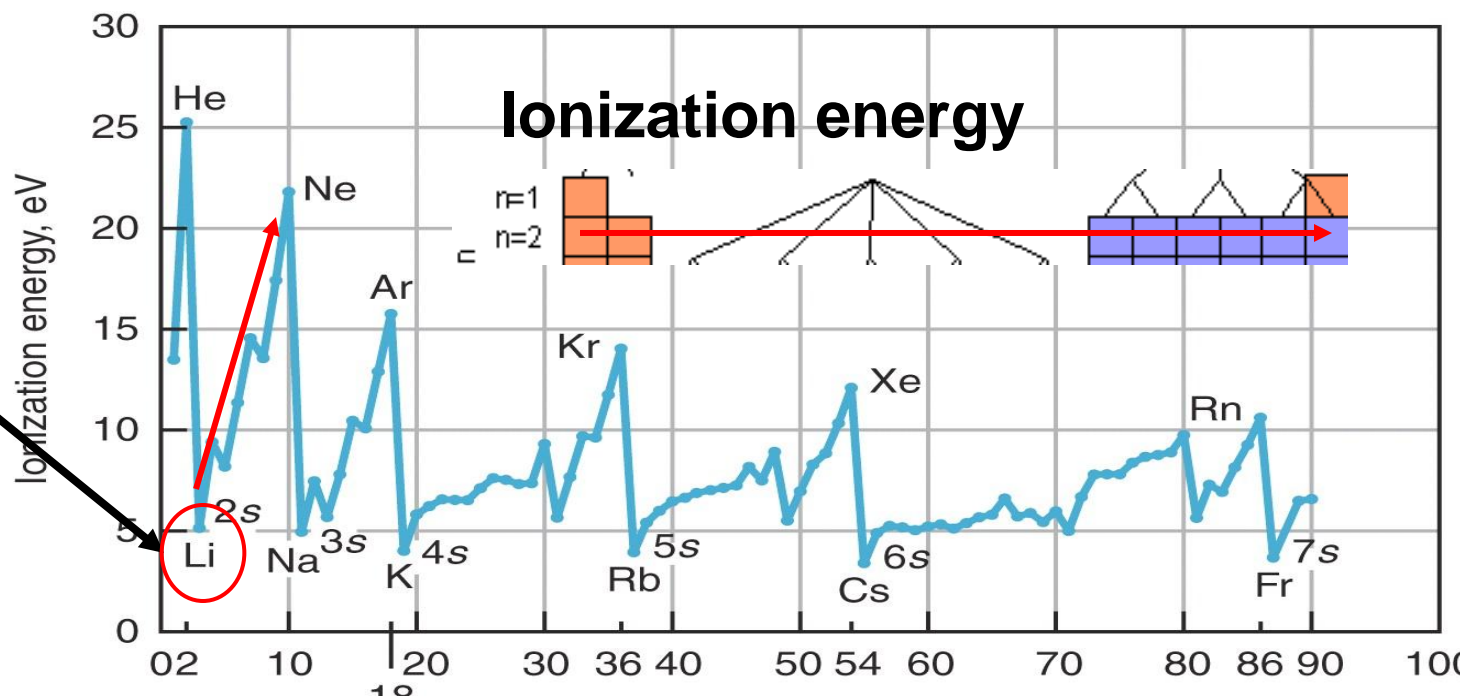
Schrodinger predicts wave functions and energies of these wave functions.



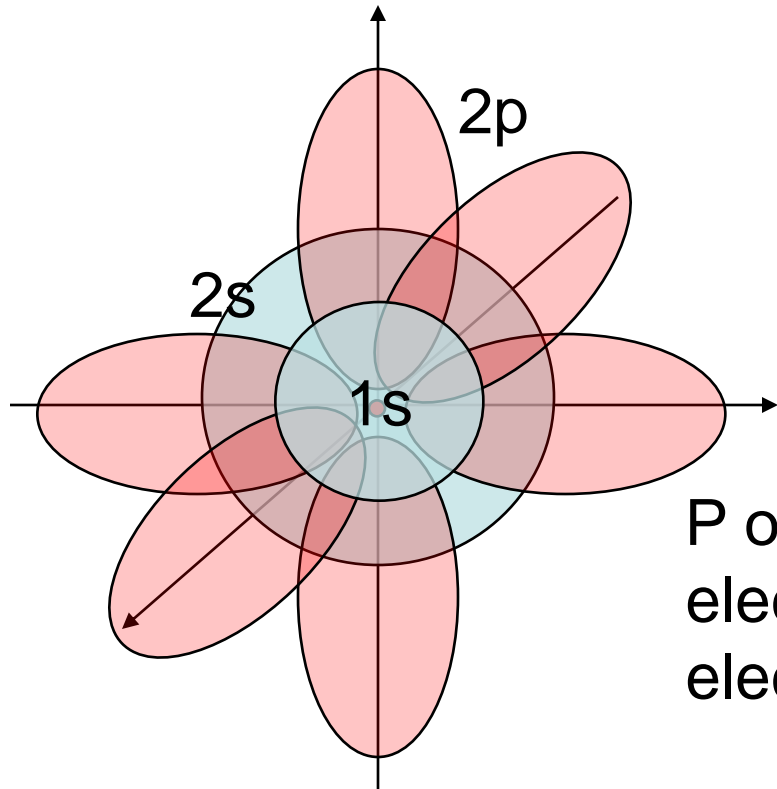
Why would behavior of Li be similar to Na?

- because shape of outer most electron is similar.
- because energy of outer most electron is similar.
- both a and b
- some other reason

Why does ionization energy increase and size decrease as add electrons in p orbitals?



1												18						
1	1 <b>H</b> 1.008											2 <b>He</b> 4.003						
2	3 <b>Li</b> 6.941	4 <b>Be</b> 9.012											5 <b>B</b> 10.81	6 <b>C</b> 12.01	7 <b>N</b> 14.01	8 <b>O</b> 16.00	9 <b>F</b> 19.00	10 <b>Ne</b> 20.18
3	11 <b>Na</b> 22.99	12 <b>Mg</b> 24.31	3	4	5	6	7	8	9	10	11	12	13 <b>Al</b> 26.98	14 <b>Si</b> 28.09	15 <b>P</b> 30.97	16 <b>S</b> 32.07	17 <b>Cl</b> 35.45	18 <b>Ar</b> 39.95



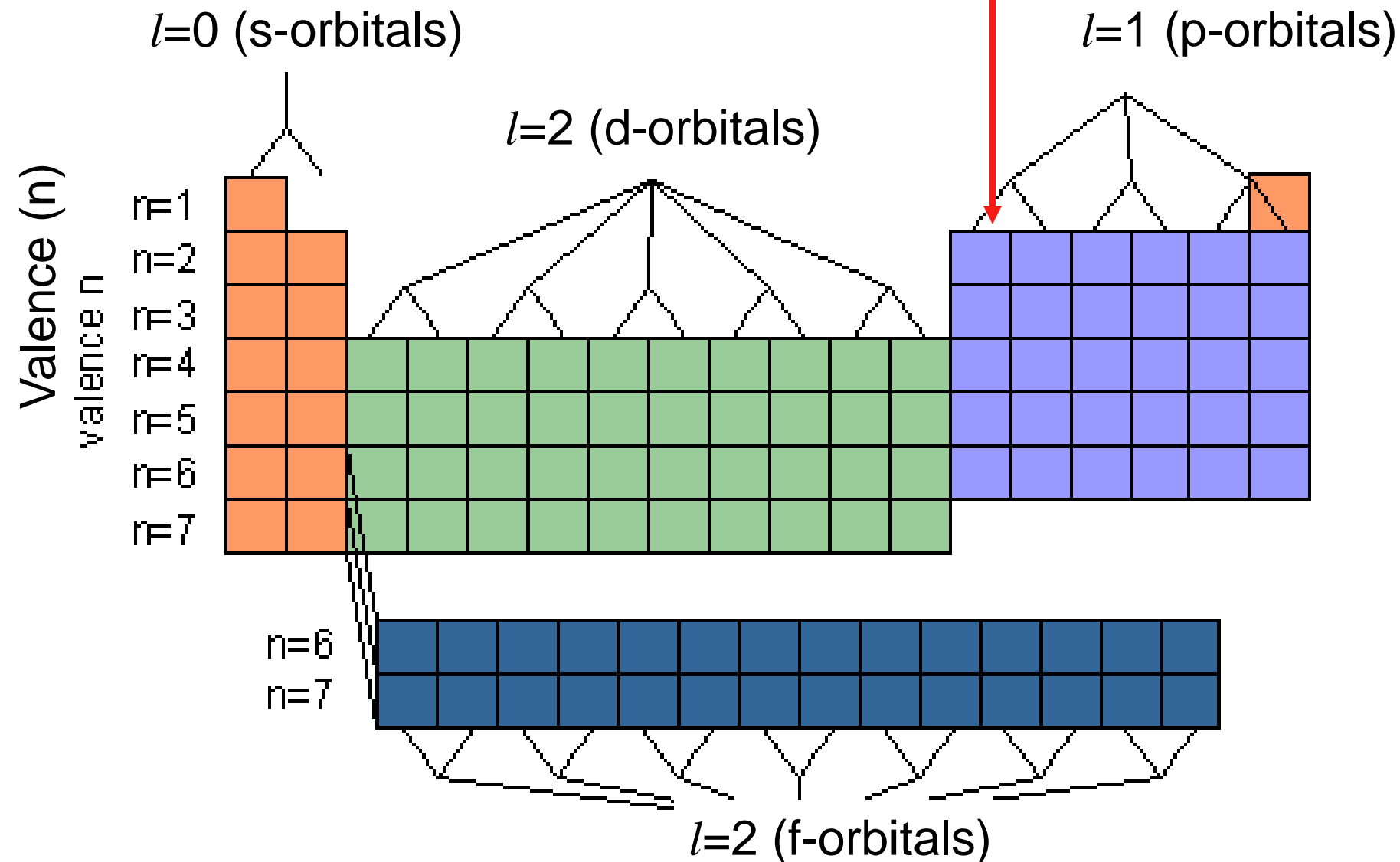
As go from Li to N,  
end up with 3 electrons in 2p (one  
in each orbital),  
Why is ionization energy larger  
and size smaller than in Li?  
(Develop reasoning)

P orbitals each have direction...  
electrons in  $p_x$  do not effectively shield  
electrons in  $p_y$  from the nucleus.

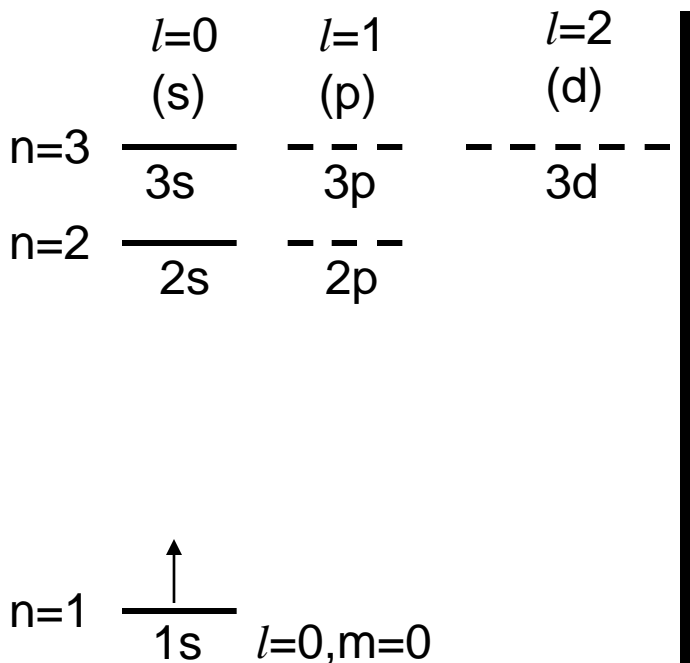
So electrons in p orbitals:

1. feel larger effective positive charge
2. are held closer to nucleus.

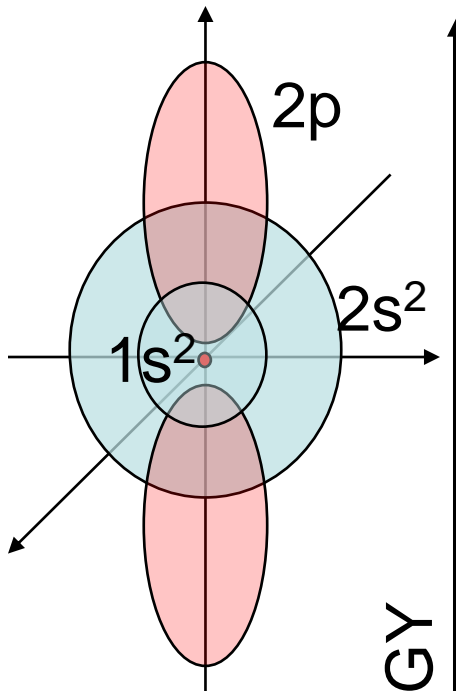
All atoms in this row have common filling of outer most shell (valence electrons), common shapes, similar energies ... so similar behavior



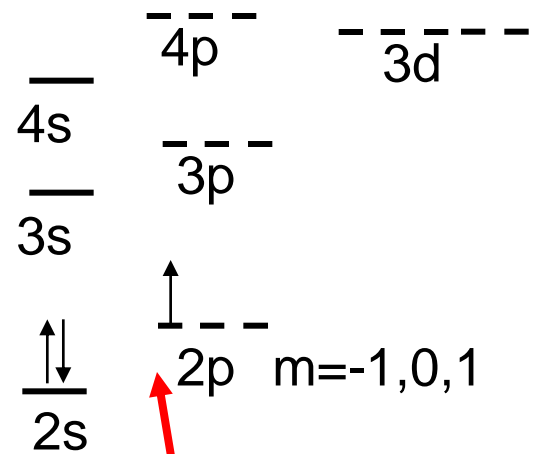
# Hydrogen (1p, 1e)



Energy only depends on n



# Boron (5p, 5e's) NOT TO SCALE!

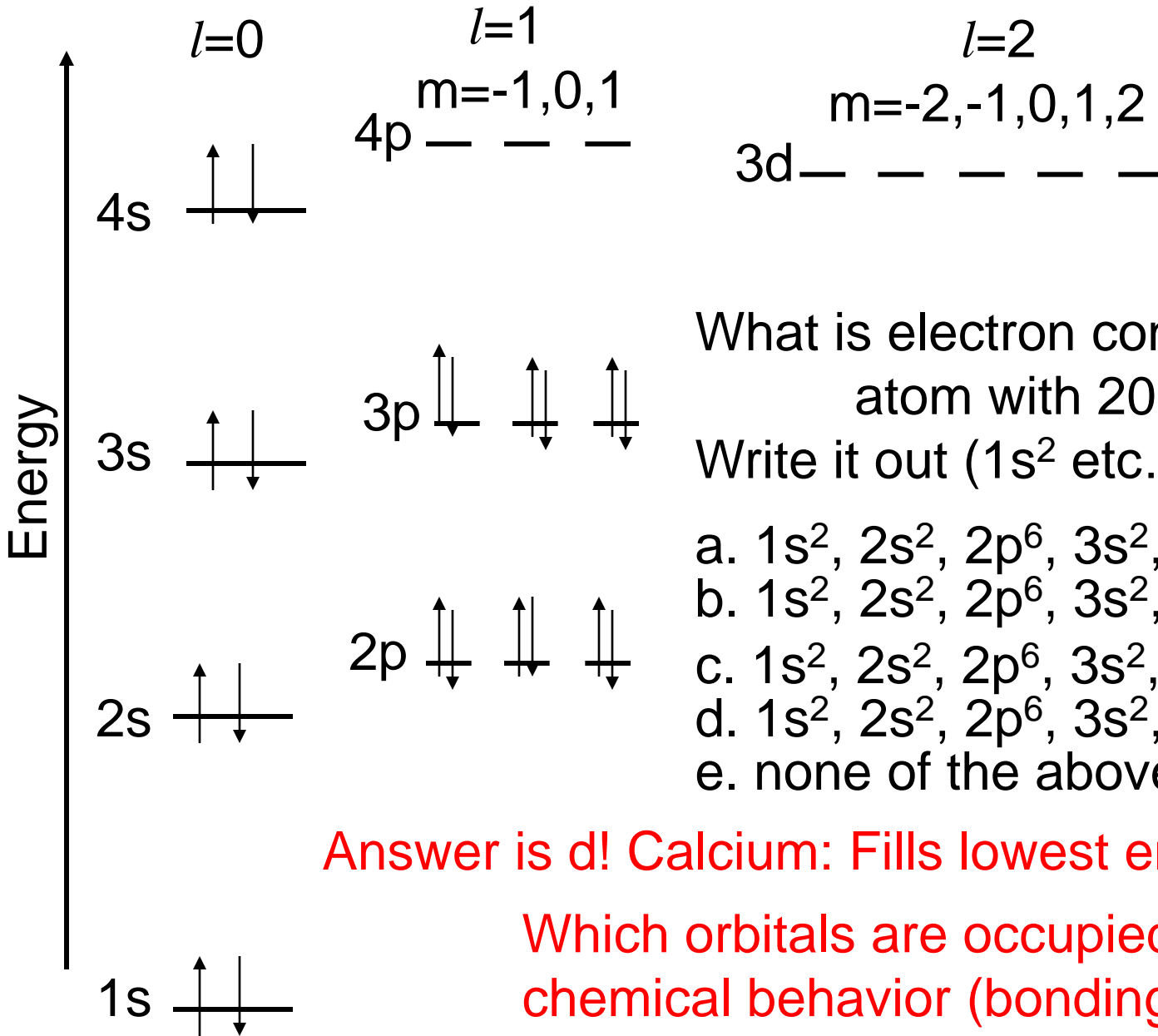


Splitting of s and p energy levels (shielding)

Energy depends on n and l



In multi-electron atoms, energy of electron level depends on  $n$  and  $l$  quantum numbers:



What is electron configuration for atom with 20 electrons?

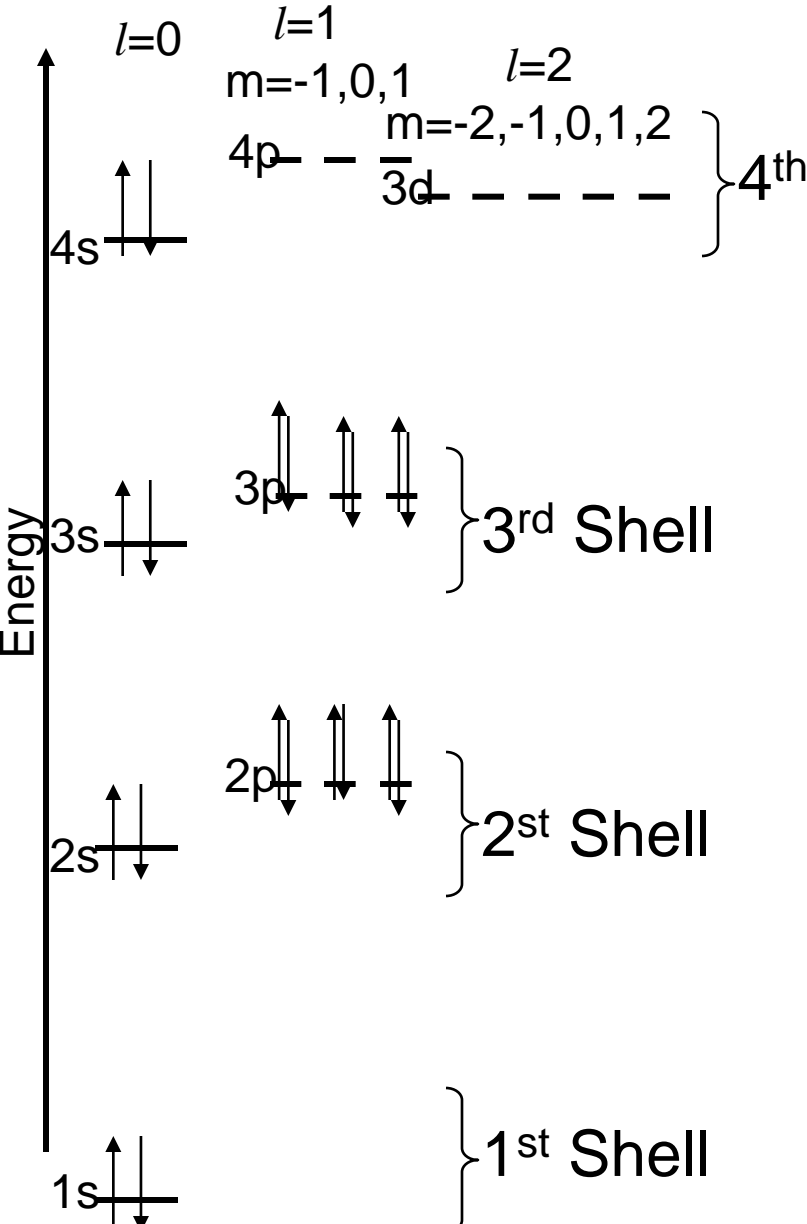
Write it out ( $1s^2$  etc... !)

- $1s^2, 2s^2, 2p^6, 3s^2, 3p^4$
- $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^2$
- $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^6$
- $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2$
- none of the above

Answer is d! Calcium: Fills lowest energy levels first

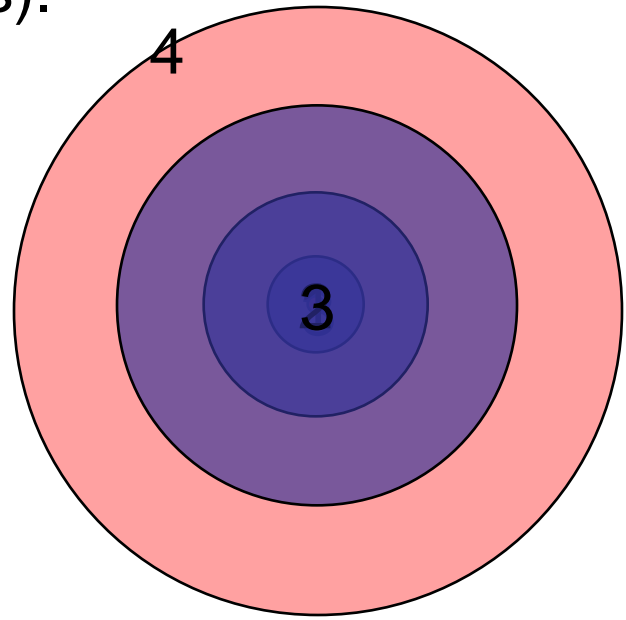
Which orbitals are occupied effects:  
chemical behavior (bonding, reactivity, etc.)

In multi-electron atoms, energy of electron level depends on  $n$  and  $l$  quantum numbers:



Calcium has 3 complete shells.

Incomplete shell:  
Chemical behavior & bonding determined by electrons in outer most shell (furthest from the nucleus).



# Electronic structure of atom determines its form

(metal, semi-metal, non-metal):

- related to electrons in outermost shell
- how these atoms bond to each other

Atomic number

Symbol

Atomic weight

Metal

Semimetal

Nonmetal

### Semiconductors

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 <b>H</b> 1.008	2 <b>He</b> 4.003											5 <b>B</b> 10.81	6 <b>C</b> 12.01	7 <b>N</b> 14.01	8 <b>O</b> 16.00	9 <b>F</b> 19.00	10 <b>Ne</b> 20.18
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11 <b>Na</b> 22.99	12 <b>Mg</b> 24.31	3 <b>Sc</b>	4 <b>Ti</b>	5 <b>V</b>	6 <b>Cr</b>	7 <b>Mn</b>	8 <b>Fe</b>	9 <b>Co</b>	10 <b>Ni</b>	11 <b>Cu</b>	12 <b>Zn</b>	31 <b>Ga</b> 69.72	32 <b>Ge</b> 72.61	33 <b>As</b> 74.92	34 <b>Se</b> 78.96	35 <b>Br</b> 79.90	36 <b>Kr</b> 83.80
19 <b>K</b> 39.10	20 <b>Ca</b> 40.08	21 <b>Sc</b> 44.96	22 <b>Ti</b> 47.88	23 <b>V</b> 50.94	24 <b>Cr</b> 52.00	25 <b>Mn</b> 54.94	26 <b>Fe</b> 55.85	27 <b>Co</b> 58.93	28 <b>Ni</b> 58.69	29 <b>Cu</b> 63.55	30 <b>Zn</b> 65.39	49 <b>In</b> 114.8	50 <b>Sn</b> 118.7	51 <b>Sb</b> 121.8	52 <b>Te</b> 127.6	53 <b>I</b> 126.9	54 <b>Xe</b> 131.3
37 <b>Rb</b> 85.47	38 <b>Sr</b> 87.62	39 <b>Y</b> 88.91	40 <b>Zr</b> 91.22	41 <b>Nb</b> 92.91	42 <b>Mo</b> 95.94	43 <b>Tc</b> 98.91	44 <b>Ru</b> 101.1	45 <b>Rh</b> 102.9	46 <b>Pd</b> 106.4	47 <b>Ag</b> 107.9	48 <b>Cd</b> 112.4	81 <b>Tl</b> 204.4	82 <b>Pb</b> 207.2	83 <b>Bi</b> 209.0	84 <b>Po</b> 209.0	85 <b>At</b> 210.0	86 <b>Rn</b> 222.0
55 <b>Cs</b> 132.9	56 <b>Ba</b> 137.3	71 <b>Lu</b> 175.0	72 <b>Hf</b> 178.5	73 <b>Ta</b> 180.9	74 <b>W</b> 183.8	75 <b>Re</b> 186.2	76 <b>Os</b> 190.2	77 <b>Ir</b> 192.2	78 <b>Pt</b> 195.1	79 <b>Au</b> 197.0	80 <b>Hg</b> 200.6						
87 <b>Fr</b> 223.0	88 <b>Ra</b> 226.0	103 <b>Lr</b> 262.1	104 <b>Rf</b> 261.1	105 <b>Db</b> 262.1	106 <b>Sg</b> 263.1	107 <b>Bh</b> 264.1	108 <b>Hs</b> 265.1	109 <b>Mt</b> 268									
		57 <b>La</b> 138.9	58 <b>Ce</b> 140.1	59 <b>Pr</b> 140.9	60 <b>Nd</b> 144.2	61 <b>Pm</b> 146.9	62 <b>Sm</b> 150.4	63 <b>Eu</b> 152.0	64 <b>Gd</b> 157.3	65 <b>Tb</b> 158.9	66 <b>Dy</b> 162.5	67 <b>Ho</b> 164.9	68 <b>Er</b> 167.3	69 <b>Tm</b> 168.9	70 <b>Yb</b> 173.0		
		89 <b>Ac</b> 227.0	90 <b>Th</b> 232.0	91 <b>Pa</b> 231.0	92 <b>U</b> 238.0	93 <b>Np</b> 237.0	94 <b>Pu</b> 244.1	95 <b>Am</b> 243.1	96 <b>Cm</b> 247.1	97 <b>Bk</b> 247.1	98 <b>Cf</b> 251.1	99 <b>Es</b> 252.0	100 <b>Fm</b> 257.1	101 <b>Md</b> 258.1	102 <b>No</b> 259.1		