

## Lecture #6

Reading:

1.10- Electron Spin

1.11- The electronic structure of hydrogen

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Topics:	I. RPD for s-orbitals (continued from Lecture #6)
	II. p-orbitals
	A. The shape of p-orbitals
	B. Radial probability distributions
	III. Electron spin and the fourth quantum number
	IV. Wavefunctions for multielectron atoms

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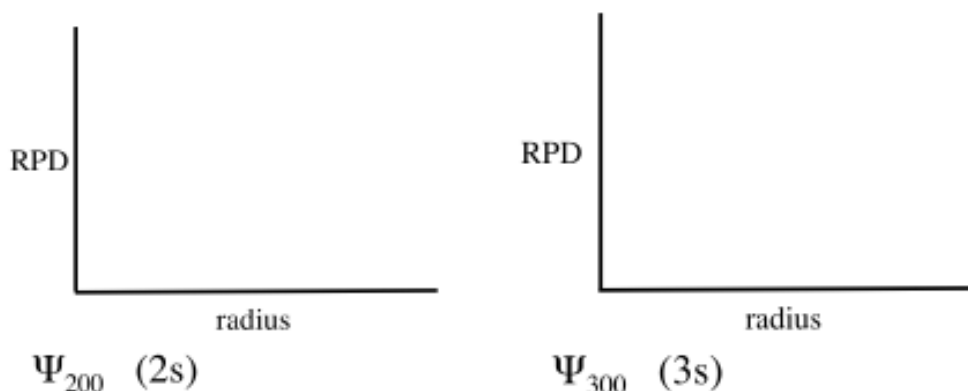
### I. RADIAL PROBABILITY DISTRIBUTIONS (RPD) FOR S-ORBITALS

**Radial Probability Distribution:** The probability of finding an electron in a spherical shell of thickness  $dr$  at a distance  $r$  from the origin.

$$\Psi^2 \times 4\pi r^2 dr = \text{RPD}$$

$$\frac{\text{probability}}{\text{volume}} \times \frac{\text{volume}}{\text{volume}} = \text{probability}$$

Knowing only probability is one of main consequences of Quantum Mechanics. Unlike CM, QM is non-deterministic. The uncertainty principle forbids us from knowing  $r$  exactly.



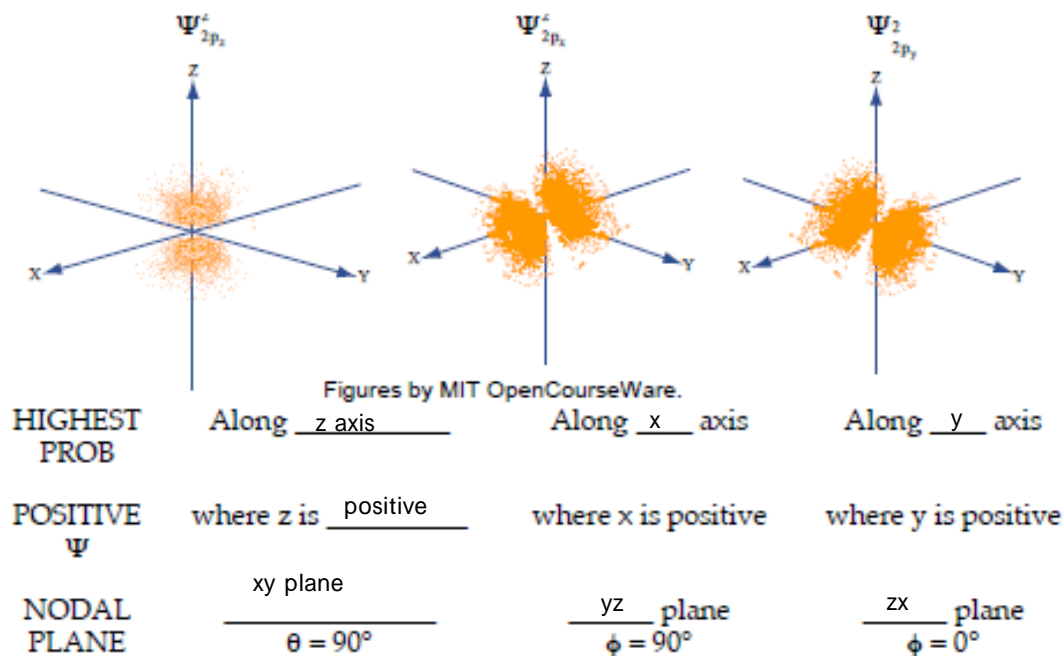
### II. P ORBITALS

- For any subshell of  $l = 1$ , there are three p-orbitals,  $\underline{p_x}$ ,  $\underline{p_y}$ , and  $\underline{p_z}$ .
- $m = \pm 1$  states combine to give  $p_x$  and  $p_y$  orbitals.  $m = 0$  is called the  $p_z$  orbital.

## A. THE SHAPE OF P-ORBITALS

- Unlike s orbitals, p-orbitals have  $\theta, \phi$  dependence. P-orbitals \_\_\_\_\_ are not spherically symmetrical.
- p orbitals consist of two lobes (of opposite sign) separated by a \_\_\_\_\_ nodal plane on which  $\Psi = 0$  (and  $\Psi^2 = 0$ ).
- There is zero probability of finding a p-electron in a nodal plane. Thus, there is \_\_\_\_\_ zero probability of finding a p-electron at the nucleus.

Probability density maps of p orbitals:



Nodal planes (planes that have no electron density) arise from angular nodes in the wavefunction.

- Angular nodes: values of \_\_\_\_\_ or \_\_\_\_\_ at which  $\Psi$  (and  $\Psi^2$ ) = 0.
- Recall from Lecture #6: Radial nodes are values of  $r$  at which  $\Psi$  (and  $\Psi^2$ ) = 0.

In general, an orbital has:

$n - 1$  total nodes  
1 angular nodes  
 $n - 1 - 1$  radial nodes

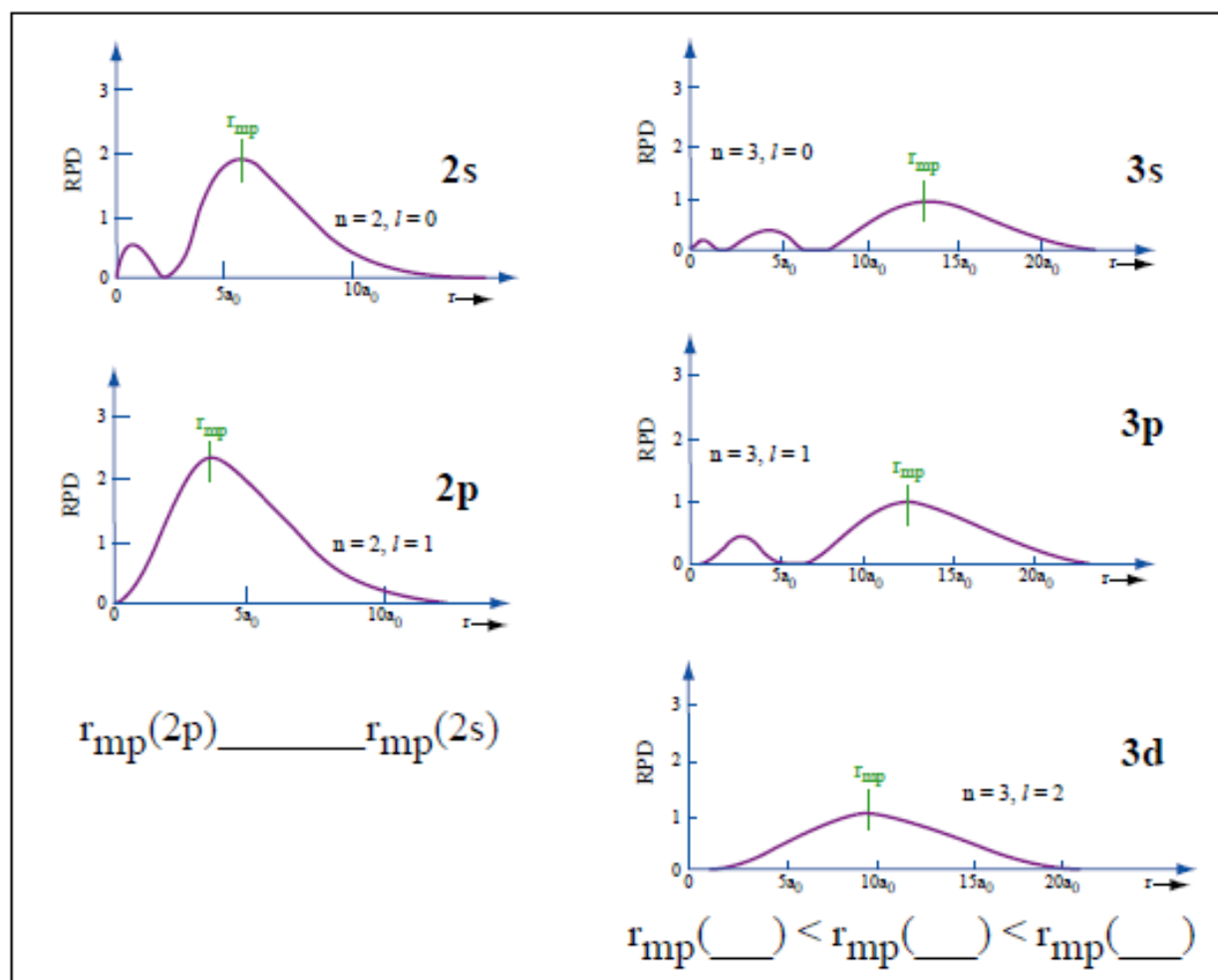
For 2s:  $2 - 1$  = 1 total nodes  
0 = 0 angular nodes

For 2p: \_\_\_\_\_ = \_\_\_\_\_ total nodes  
1 = 1 angular nodes

\_\_\_\_\_ = \_\_\_\_\_ radial nodes

\_\_\_\_\_ = \_\_\_\_\_ radial nodes

## B. RADIAL PROBABILITY DISTRIBUTIONS



Figures by MIT OpenCourseWare.

### Interpreting RPD plots

- As  $n$  increases (from 1 to 2 to 3), the orbital  $r_{mp}$  "size" \_\_\_\_\_ increases \_\_\_\_\_.
- As  $l$  increases (from s to p to d) for a given  $n$ , the orbital  $r_{mp}$  "size" \_\_\_\_\_ decreases \_\_\_\_\_.
- Only electrons in s states have a substantial probability of being very close to nucleus. This means that although the "size" of s orbitals is larger than p or d orbitals, s-electrons are the \_\_\_\_\_ least \_\_\_\_\_ shielded.

## III. ELECTRON SPIN AND THE FOURTH QUANTUM NUMBER

From quantum mechanics, a fourth quantum number appears that describes the spin of an electron within an orbital.

Spin magnetic quantum number,  $m_z$  \_\_\_\_\_

There is no classical analogy to spin.

- An electron can have two spin states:  
 $m_s = +1/2$  (spin up) or  $m_s = -1/2$  (spin down).
- Similar to the angular momentum quantum number,  $l$ ,  $m_s$  describes the magnitude of an angular momentum. However,  $m_s$  completes the description of an electron and is NOT dependent on the orbital.

The property of electron spin was first proposed by S. Goudsmit and G. Uhlenbeck in 1925 to explain tiny deviations from the expected frequencies of spectral lines:



So we can describe a given orbital using three quantum numbers ( $n, l, m_l$ ) and a given electron using 4 quantum numbers ( $n, l, m_l, m_s$ ).

$\Psi_{n/m_l}$   
describes an orbital

$\Psi_{n/m_l/m_s}$   
describes an electron

### PAULI EXCLUSION PRINCIPLE

No two electrons in the same atom can have the same four quantum numbers. In other words, no two electrons can be in the same orbital and have the same spin.

The Pauli exclusion principle limits an atom to two electrons per orbital.

ie. How many *electrons* in a single atom can have the following two quantum numbers:  $n = 4$  and  $m_l = -2$ ?