CH301H – Principles of Chemistry I: Honors
Fall 2015, Unique 49310

Exam 3
27 October 2015

Name: Key

You may use any material you wish provided it does not have a heartbeat nor does it connect to a wireless or cellular network.

Honor Code:

"The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community "

I certify that the work on this exam is entirely my own.

Signature Date

1. (21 points) Determine whether the following statements are true or false.

a. True (False) The Schrodinger equation cannot be used for any atom that has more than one electron.

b. (True) False $f(x) = \cos\theta$ is an eigen function for the operation $\frac{\partial^2 f(x)}{\partial x^2}$

c. (True) False In a one-electron atom, energy is inversely proportional to the principal quantum number *n*.

d. True (False) The Schrodinger equation assumes energy is quantized.

e. True (False) In any atomic orbital, the sum of the number of radial nodes and angular nodes equals the principal quantum number.

f. True (False) Violations to the Pauli exclusion principle are allowed, but result in an atom that is higher in energy than the lowest available ground state.

g. (True) False The $n = 2$ state contains a maximum of eight electrons.

2. (18 points) The first ionization energy of He is 24.6 eV/atom (the highest observed for any element). You wish to ionize He by illuminating it with light. What is the maximum wavelength of light you could use to do this?

$$E = \frac{24.6\,eV}{atom}\left(\frac{1.602\times10^{-19}\,J}{eV}\right) = 3.94\times10^{-18}\,J$$

$$E = \frac{hc}{\lambda} \qquad \lambda = \frac{hc}{E} = \frac{(6.626\times10^{-34}\,Js)(3.0\times10^{8}\,m/s)}{3.94\times10^{-18}\,J}$$

$$\boxed{\lambda = 5.04\times10^{-8}\,m}$$

3. (21 points) The angular part of the d_{z^2} wavefunction is given below:

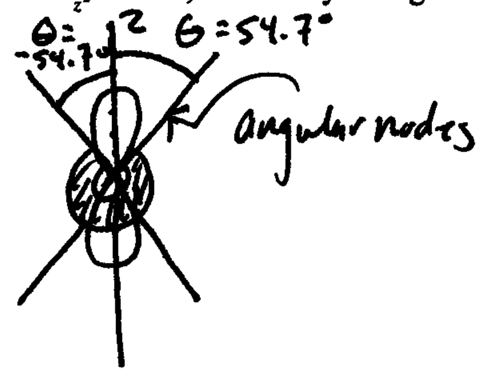
$$Y_{d_z^2} = \left(\frac{5}{16\pi}\right)^{1/2}\left(3\cos^2\theta - 1\right)$$

a) Draw a d_{z^2} orbital with no radial nodes.

b) How many angular nodes does this orbital have?

d orbital => $l = 2$ ∴ 2 angular nodes

c) Draw the angular nodes on the d_{z^2} orbital, either on your figure in part a) above, or a new figure here.

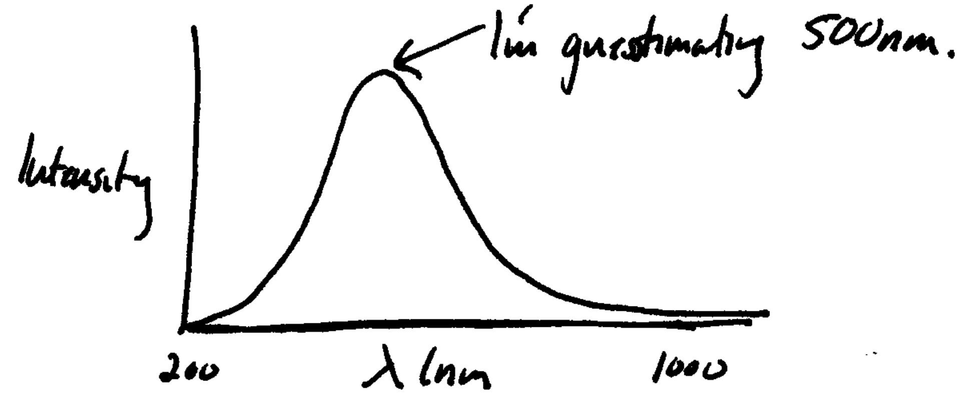


d) What angles describes the angular nodes that you have drawn in part c)?

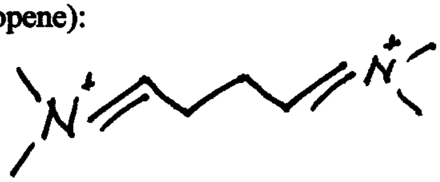
Angular nodes appear where $Y(\theta,\phi) = 0$. In the function given above, this will happen at $3\cos^2\theta = 1$, or $\cos\theta = \sqrt{\frac{1}{3}}$. This occurs at $\theta = \pm 54.7°$ or ± 0.955 radians. I have drawn this above. (BTW, for reasons well outside the scope of this class, this angle shows up in interesting places in the physical world. It's actually called the "magic angle.")

4. (22 points) The molecule lycopene is the pigment that gives tomatoes their bright red color.

a) Estimate what the absorption spectrum of lycopene looks like and name the wavelength of maximum absorption. Lycopene looks red, so it absorbs blue.



b) Lycopene has a molecular structure that is similar to the following molecule (this is NOT the actual structure of lycopene):



If you consider the electron that is being excited in the absorption spectrum you drew in part a) above to be a particle in a box of length *L* defined by the distance between the two N atoms in the molecule above, how long is the box?

$E = \frac{n^2 h^2}{8 m_e L^2}$ The change in energy between $n=1$ and $n=2$ is 500nm

$$\Delta E = E_f - E_i = \frac{n(2)^2 h^2}{8 m_e L^2} - \frac{n(1)^2 h^2}{8 m_e L^2} = \frac{h^2}{8 m_e L^2}\left(n(2)^2 - n(1)^2\right) = \Delta E$$

$$\lambda = 500\text{nm},\ \Delta E = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\ Js)(3.0\times10^{8}\ m/s)}{500\times10^{-9}\ m} = 3.9\times10^{-19}\ J$$

$$L = \left[\frac{h^2}{8 m_e \Delta E}(2^2 - 1^2)\right]^{1/2} = \left[\frac{(6.626\times10^{-34} Js)^2}{8(9.1\times10^{-31}\ kg)(3.9\times10^{-19} J)}(4-1)\right]^{1/2}$$

$$\boxed{L = 6.8\times10^{-10}\ m = 6.8\ \text{Å}}$$

(So about 6 bonds long - Sounds reasonable.)

5. (18 points) Which of the following collections of quantum numbers:

i) Determine if the set of quantum numbers is allowed.
ii) If your answer to the first question is "yes," name the atomic orbital described by the set of quantum numbers.

a) $n = 4, l = 0, m = 0, m_s = +1/2$ Yes 4s

b) $n = 1, l = 1, m = 1, m_s = +1/2$ No

c) $n = 2, l = 0, m = 0, m_s = -1/2$ Yes 2s

d) $n = 3, l = 1, m = -1, m_s = 1$ No

e) $n = 2, l = -1, m = -1, m_s = -1/2$ No

f) $n = 3, l = 2, m = -2, m_s = -1/2$ Yes 3d

g) $n = 4, l = 2, m = 1, m_s = +1/2$ Yes 4d

h) $n = 15, l = 14, m = -12, m_s = +1/2$ Yes 15r