CH 101Fall 2018
Discussion #12
Chapter 8, Mahaffy, 2e sections 8.3-8.7

Your name: ______________________ TF's name:______________________ Discussion Day/Time: __________

Things you should know when you leave Discussion today for one-electron atoms:

- $E_n = (-R_y)\frac{Z^2}{n^2} = (-2.179 \cdot 10^{-18}\text{J})\frac{Z^2}{n^2} = (-13.6\text{ eV})\frac{Z^2}{n^2}$
- $\Delta E_{matter} = E_n - E_m$; Ionization Energy(IE)=$E_\infty - E_{n(initial)}$
- $\Delta E_{light} = h\nu_{light} = \text{IE} + \text{KE}$

1. Consider the following energy levels of the hydrogen atom as shown below in the diagram:
   a. Sketch electron clouds corresponding to energy levels up to $n = 3$:

   b. When electron cloud of the H atom at the lowest energy interacts with light of the lowest resonate frequency, sketch the resulting electron cloud(s):

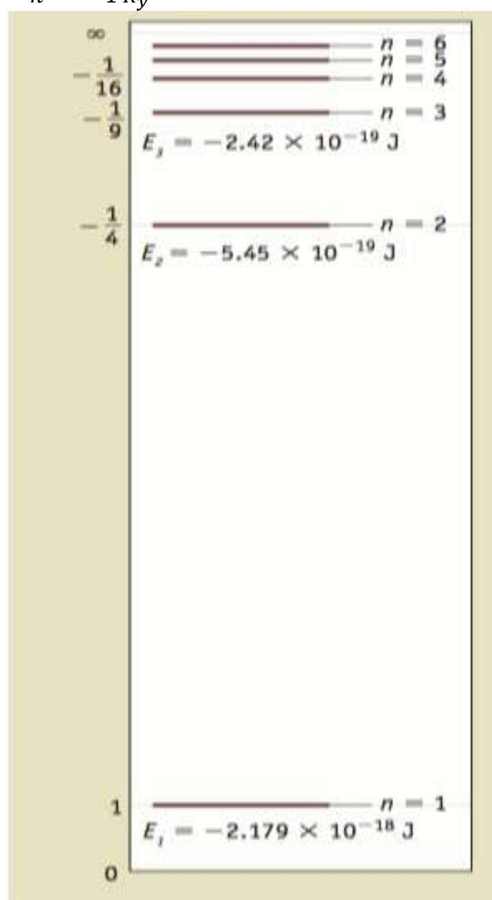
   c. When electron cloud of the H atom at the lowest energy interacts with light of the 2nd lowest resonate frequency, sketch the resulting electron cloud(s):

   d. When electron cloud of the He atom at the lowest energy interacts with light of the lowest resonate frequency, sketch the resulting electron cloud(s):

   e. What are the two energy levels involved in the ionization energy of an electron from H in the ground state?

   f. What is the ground state H atom ionization energy in J, eV and kJ/mol?
   $H(g) \rightarrow H^+(g) + e^-$

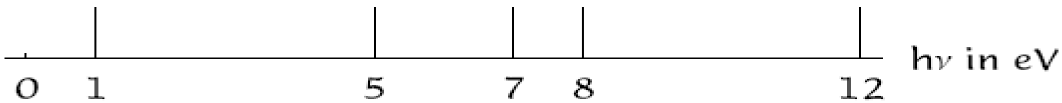
$$\frac{1}{n^2} = \left(\frac{E}{1 \cdot R_y}\right)$$



   g. What is the expression for the ionization energy of an electron from the $n = 3$ state of a one electron atom with atomic number Z?

2. Hypothetical atom, X, has the following **ground state absorption** spectrum displayed below, and the ground state ionization energy of the atom is 15 eV (IE). Each of the **absorption** lines corresponds to a natural frequency of the electron cloud resulting from the mixing of electron wave with 1 loop with electron wave with more than one loop (i.e**. the atom always starts in its ground state during each absorption**). In answering the following questions, assume that the zero of energy is the ionized atom

$$X \rightarrow X^{+} + e^{-}$$



a. What is the energy of the ground state (of the electron cloud corresponding to one loop) of X? *Hint: pay attention to the sign*

b. Construct the energy level diagram for X. Hint: How many energy levels are necessary to account for the **absorption** spectrum?

c. Using the energy level diagram you just drew: How many emissions **are possible** in the electrically-excited emission spectrum of this atom?

d. What is the energy of the *third excited* state of X? How many loops does that state have?

e. What is the energy of the *highest energy state* of X that is necessary to account for the **absorption** spectrum?

f. Is it possible for an electron in the ground state of atom X to absorb light of energy 3 eV or will it be transparent to it?

g. Can atom X emit light of energy 3 eV?

h. Is it possible for X to absorb light of energy 16 eV or will it be transparent to it? Why?

i. Can atom X emit light of energy16 eV?

j. What is the lowest frequency of the light emitted from the atom?

k. Draw the emission spectrum:

l. **At home:** Calculate the kinetic energy of an electron (in Joules) that was ionized by light of frequency of $5 \cdot 10^{15}$ Hz from the ground state. *Hint: Remember that energy must be conserved.* ($1.6021766 \cdot 10^{-19}$ J = 1 eV)

3. What is the expression for the energy (in J) for the ground state of an electron cloud in Li^{2+}?

   a. Calculate wavelength (in nm) of the light corresponding to the Li^{2+} electron cloud resulting from mixing a 3 loop electron wave with a 1 loop electron wave?

4. Photons of energy 13.6 eV = R_y are able to ionize H in its $n = 1$ energy level. Are photons of this energy are able to ionize He^+ in its $n = 2$ energy level?

5. The photoelectric effect threshold frequency of a metal is $\upsilon_0 = 1 \cdot 10^{15}$ Hz. Gamma radiation of frequency $1 \cdot 10^{17}$ Hz ejects electrons from the metal. Which of the following occurs when the intensity of the gamma radiation is reduced by 50.%?

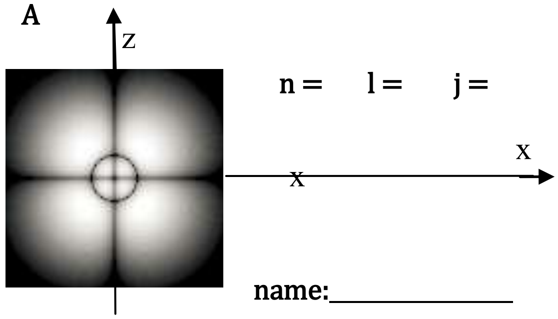
   a. The velocity of the ejected electrons will be reduced by a factor of two.
   b. The kinetic energy of the ejected electrons will be reduced by a factor of two.
   c. The kinetic energy of the ejected electrons will be reduced by a factor of four.
   d. Kinetic energy and the velocity of the ejected electrons will stay the same.
   e. Number of ejected electrons will increase.
   f. Number of ejected electrons will decrease.

6. Assume light is able to eject electrons from a metal. What do you expect as the wavelength of the light is increased?
   a. If the light wavelength reaches the lowest, electrons will no longer be ejected.

b. Electrons will still be ejected but they will move faster and faster.
c. Electrons will still be ejected but they will move slower and slower.
d. More and more electrons will be ejected but they will have the same kinetic energy.
e. More information needed.

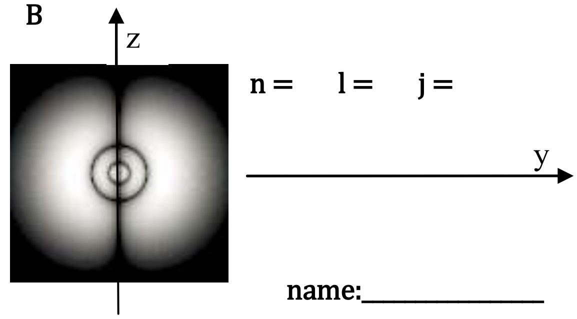
7. One atom emits light of energy 1.27 eV. A second atom has only three energy levels: -0.9 eV, -1.27 eV, and -1.9 eV. Assuming ionization is not possible can the second atom absorb the light emitted by the first atom.

8. For the two hydrogen electron clouds below identify the quantum number "n", the quantum number "l", the number of radial loops "j", and the specific name of the orbital (you must indicate orientation, e.g. $3d_{xy}$).



n = l = j =

name:_______________



n = l = j =

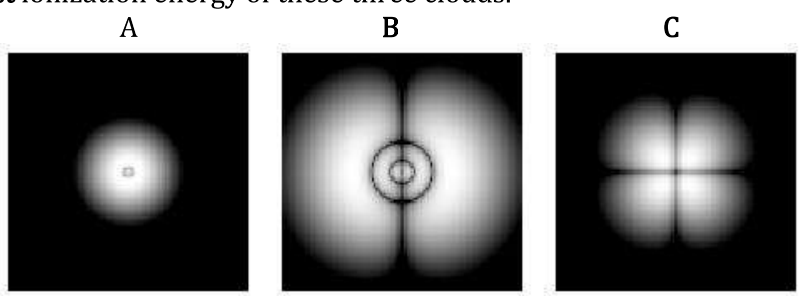
name:_______________

a. For the two hydrogen electron clouds above, which has the largest ionization energy? *Note: in H atom, all orbital of the same n have the same energy.*

9. What are the possible angular momentum quantum numbers for an orbital in the n=4 shell?

a. How many **degenerate** orbitals are in the n=3 shell? What are they? Note: in H atom, all orbitals of the same *n* have the same energy.

10. The figure shows three H atom electron clouds.
a. Which of the following H atom electron clouds has the largest ionization energy?
b. Write down the **numerical expression** that when evaluated gives the value **in eV** of **smallest** ionization energy of these three clouds.



Things you should know when you leave Discussion today for multi-electron atoms:

- Many electron system Mahaffy, 2e section 8.4
- Electron configurations Mahaffy, 2e section 8.5

- Shielding and effective nuclear charge: Mahaffy, 2e section 8.6
  - $E_n = (-R_y)\frac{Z_{eff}^2}{n^2} = (-13.6\text{ eV})\frac{Z_{eff}^2}{n^2} = (-2.179\cdot 10^{-18}\text{J})\frac{Z_{eff}^2}{n^2} = (-1312\frac{\text{kJ}}{\text{mol}})\frac{Z_{eff}^2}{n^2}$
- Periodicity: Mahaffy, 2e section 8.7

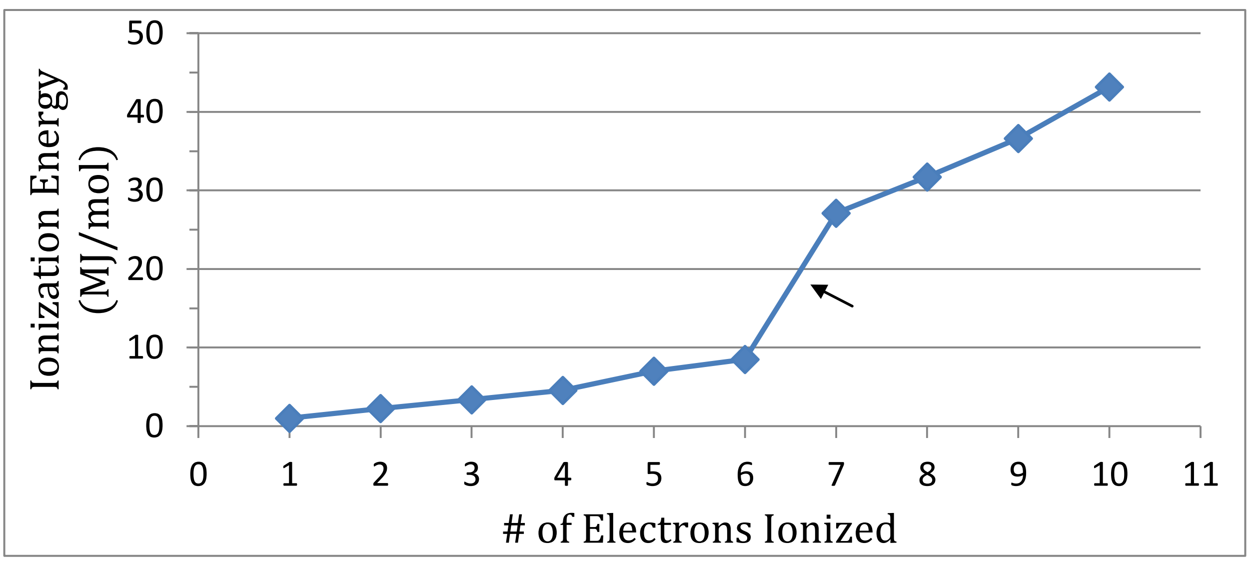
1. Below is a plot of the first 10 ionization energies for a single atom in 3rd row of the periodic table. The x-axis shows which ionization (e.g. IE_1, IE_2, etc.) and the y-axis gives how much energy in (MJ/mol).

   a. What 3rd row element does the plot show?

   b. First ionization energy IE_1 is 10.36 eV calculate Z_{eff} for that element. Note: We will not use Slater's rules for Z_{eff}, so please ignore Mahaffy et al., section 8.6, pages 289 to 291.(Useful information: $1\text{eV} = 1.6021766\cdot 10^{-19}$ J; $N_A = 6.022140857 \times 10^{23}$/mol)

   $$IE = E_\infty - E_{initial} = (2.179\cdot 10^{-18}\text{J})\frac{Z_{eff}^2}{n^2} = (13.6\text{ eV})\frac{Z_{eff}^2}{n^2} = (1312\frac{kJ}{mol})\frac{Z_{eff}^2}{n^2}$$

   c. The arrow points to the jump between the 6th and 7th ionization energy. Which of the following statements are true?
      i. The number of protons (Z) changed.
      ii. The effective nuclear charge (Z_{eff}) changed.
      iii. The quantum number n of the electron that is ionized changed.
      iv. The radius of the ion decreased



2. From the following three different neutral atoms electron configurations, label the one with the highest *third ionization energy*, and lowest *third ionization energy*. Explain your

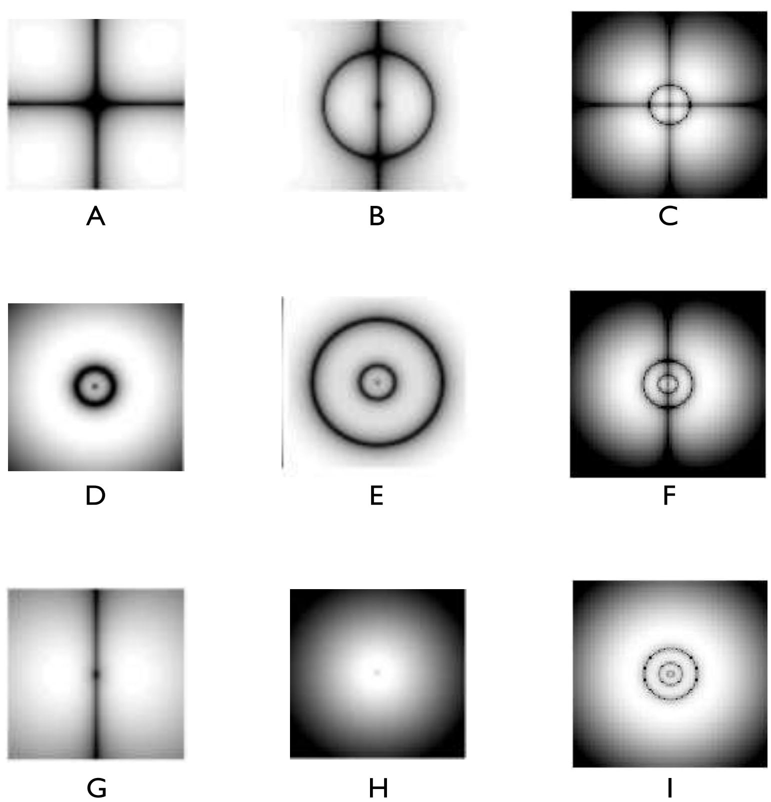
answers. Hint: remember that number of electrons in the neutral atom equals the number of protons.
a. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$
b. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$
c. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

3. Which one will have the greatest ionization energy: Na^+, Ne, F^-, O^{2-}?

4. Answer the following questions about manganese (Mn):
   a. What is the electron configuration?

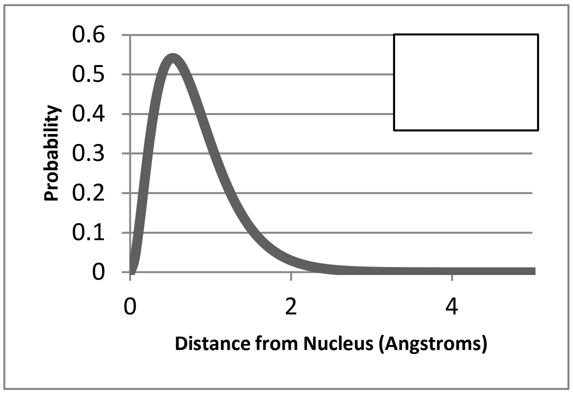
   b. First ionization energy IE_1 is 7.43 eV calculate Z_{eff} for that element.

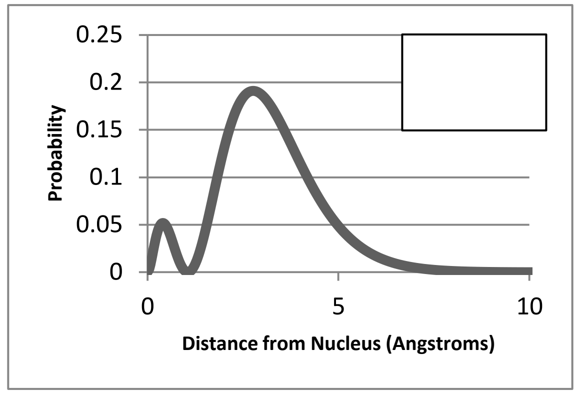
   c. Circle the letters corresponding to the picture of **occupied** electron clouds. *Hint: you need to know what are n, l, and j for one electron in each of the occupied electron clouds.*

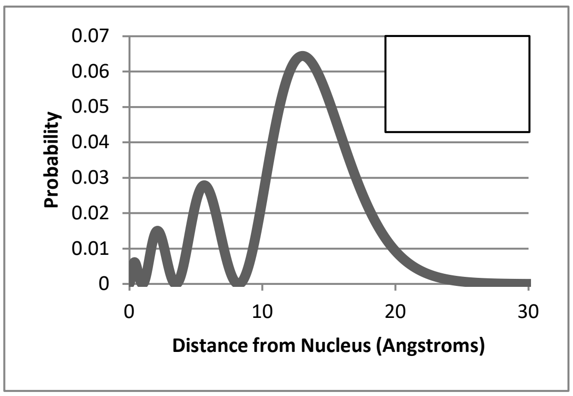


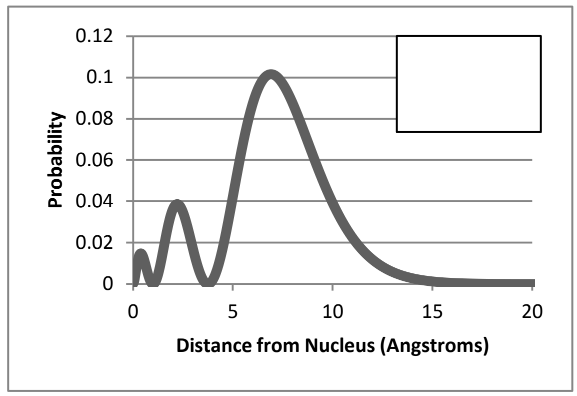
For the pictures above, fill in the empty boxes on the graphs on the next page with corresponding names of the orbitals (1s, 2s, 3s, 4s, 2p, 3p, 3d):

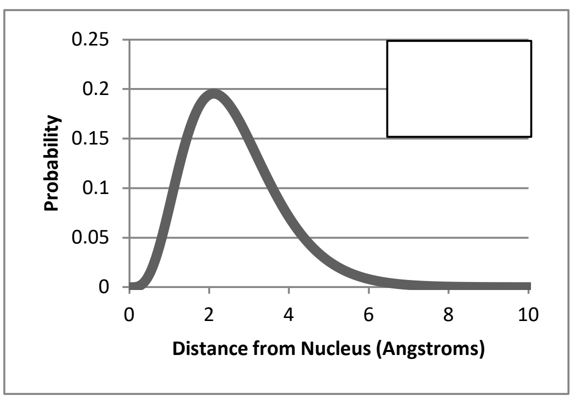
d. Use the radial probability densities on the next page (electron cloud cross section below) to **estimate** the size of an atom of Mn. Hint: Look at the x axis.

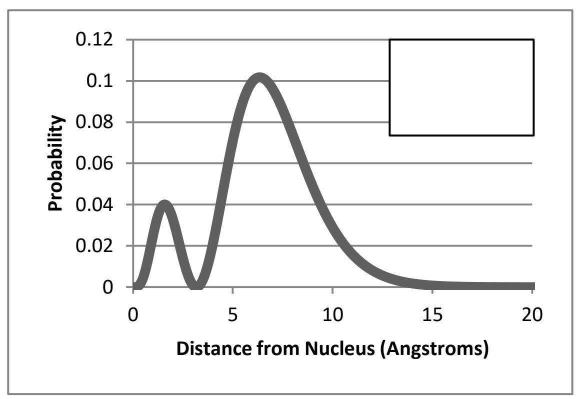




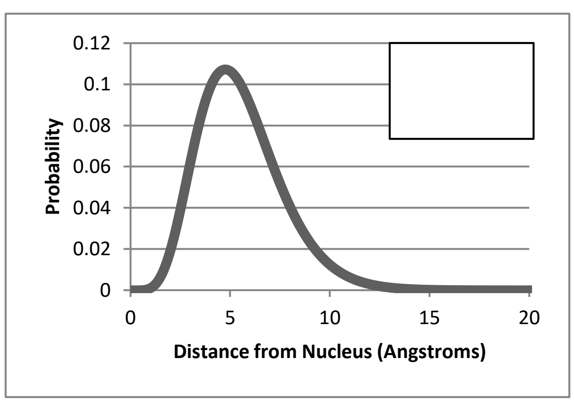








Additional Practice Problems



1. What electron cloud energies account for the line corresponding to the wavelength 434 nm in the gas discharge spectrum for the Balmer series of H atoms? (In the Balmer series in each of the emission lines corresponds to a natural frequency of the electron cloud resulting from the mixing of an electron wave with more than two loop with the electron wave with 2

loop)

A. Only the $n = 3$ cloud energy
B. Only the $n = 4$ cloud energy
C. Only the $n = 5$ cloud energy
D. The $n = 2$ and $n = 4$ cloud energies
E. The $n = 2$ and $n = 5$ cloud energies
F. None of these.

2. The ionization wavelength of H atom in the $n = 2$ energy level is 365 nm. Will light of this wavelength ionize He^+ in the $n = 1$ level?

3. The light with wavelength of 365 nm will ionize H atom in the $n = 2$ energy level. What effect will light with wavelength 657 nm have? (Choose all that apply.)
   a. Atom will be transparent to the light of this wavelength
   b. Ionization will take place
   c. Ionization will not take place
   d. The ionized electron will use excess energy for kinetic energy

4. The light with wavelength of 365 nm will ionize H atom in the $n = 2$ energy level. What effect will light with wavelength 265 nm have? (Choose all that apply.)
   a. Atom will be transparent to the light of this wavelength
   b. Ionization will take place
   c. Ionization will not take place
   d. The ionized electron will use excess energy for kinetic energy

5. An electron is ionized from the ground state of an atom, with $E_1 = -30$ eV, by light for which a photon of light energy is 36 eV. What is the kinetic energy (in eV) of the ejected electron?

6. What is kinetic energy of the electron ionized from Li^{2+} in its $n = 6$ level by light of wavelength 310 nm?

7. In terms of the variables (i.e. R_y, h, and c) what is the smallest possible wavelength of light that will be emitted by a He^+ atom starting with the energy corresponding to 6 loops?

8. What is the largest possible wavelength of light that will be emitted by be the Li^{2+} atom with the energy level corresponding to 6 loops.
9. An electron is ionized from the ground state of an atom, with $E_1 = -1.3\cdot10^{-19}$ J, by light with frequency $1.0\cdot10^{15}$ Hz. What is the kinetic energy (in eV) of the ejected electron?

10. The work function (ionization energy), of chromium metal is $7.2\cdot10^{-19}$ J.
   a. What is the maximum kinetic energy of an electron, if it is ejected from chromium metal by light of wavelength 250. nm?
   b. What will happen to the speed and quantity of the ejected electrons if the wavelength of the light will increase?
   c. What will happen to the speed and quantity of the ejected electrons if the wavelength of the light will decrease?

d. What will happen to the speed and quantity of electrons if the intensity of the light will increase?

11. An atom has only three energy levels, -2.5, -4.0, and -4.5 eV. Draw the **absorption** spectrum for a gas of these atoms excited by an electric discharge. Hint: you need to draw energy level diagrams to answer this question assume the most negative energy is an energy of the ground state

 a. Draw the **emission** spectrum. *Hint: does it always just go to the ground state?*

12. An atom has only three energy levels, -2.6, -4.1, and -5 eV. Draw the **absorption** spectrum for a gas of these atoms excited by an electric discharge.

 a. List all the lines in the **emission** spectrum. Do not assume that it always goes to the ground state.

13. An atom has energy levels of $-2.2\cdot10^{-18}$ J, $-5.5\cdot10^{-19}$ J, $-2.5\cdot10^{-19}$ J, $-1.4\cdot10^{-19}$ J, $-8.7\cdot10^{-20}$ J, and $-6.1\cdot10^{-20}$ J.
 a. Calculate the λ (in nm) of light that is necessary to excite an electron to E_∞ from E_2.
 b. What is the λ (in nm) of light necessary to excite an electron to E_3 from E_2?
 c. How many emission lines (in total) are possible for an atom with these energy levels?
 d. How many ground-state absorption lines are possible for an atom with these energy levels?
14. Draw the electron configuration diagram for C, but **fill** the diagram as if the C is in the ground state. Draw a dotted line around a shell. Circle a subshell. Draw a triangle around an orbital. Is C atom paramagnetic or diamagnetic?

 a. Calculate Z_{eff} of C, if IE_1 = 1086 kJ/mol. *(Hint: IE= E_∞-$E_{initial}$* $= (2.179 \cdot 10^{-18} J)\frac{Z_{eff}^2}{n^2}$*)*
15. Rank the following in terms of increasing ionization energy: Na, Li, B, N, Ne

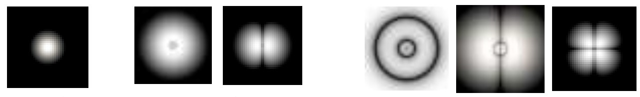
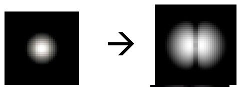
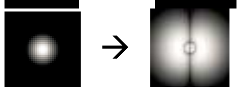
16. Rank the following in terms of increasing ionization energy: Li^+, B^+, N^+, Ne^+, Na^+

17. Write the ground state electron configuration for the following atoms and ions and determine if each is paramagnetic or diamagnetic: Al, Al^{3+}, V, V^{3+}

Atom	Z	Electron configuration	IE_1 $\left(\frac{kJ}{mol}\right)$	Z_{eff}	Trends in IE_1 is explained by: a. Z increases b. Electron –electron repulsion c. New shell d. l increases or Z_{eff} decreases (shielding)	Ions (Ions Electron configuration)
He	2	$1s^2$	2373			He^+ $1s^1$
Li	3	$1s^2 2s^1$	520			Li^+ $1s^2$
Be	4	$1s^2 2s^2$	899			Be^+ $1s^2 2s^1$
B	5	______________	801			B^+ ______________
C	6	$1s^2 2s^2 2p_x^1 2p_y^1$	1086			C^+ $1s^2 2s^2 2p_x^1$
N	7	______________	1400			N^+ $1s^2 2s^2 2p_x^1 2p_y^1$
O	8	______________	1314			O^+ $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$
F	9	$1s^2 2s^2 2p_x^2 2p_y^2 2p_z^1$	1680			F^+ ______________
Ne	10	______________	2080			Ne^+ $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^1$
Na	11	______________	496			Na^+ $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2$
Mg	12	$1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2 3s^2$ $= [Ne]3s^2$	738			Mg^+ $[Ne]3s^1$
Al	13	$[Ne]3s^2 3p_x^1$	578			Al^+ $[Ne]3s^2$

Atom	Z	Electron configuration	IE_2 $(\frac{kJ}{mol})$	Z_{eff}	Trends in IE_2 is explained by: a. Z increases b. Electron –electron repulsion c. New shell d. l increases or Z_{eff} decreases (shielding)
He	2	He^+ $1s^1$	5248		
Li	3	Li^+ $1s^2$	7300		
Be	4	Be^+ $1s^22s^1$	1757		
B	5	B^+	2430		
C	6	C^+ $1s^22s^22p_x^1$	2350		
N	7	N^+ $1s^22s^22p_x^12p_y^1$	2860		
O	8	O^+ $1s^22s^22p_x^12p_y^12p_z^1$	3390		
F	9	F^+	3370		
Ne	10	Ne^+ $1s^22s^22p_x^22p_y^22p_z^1$	3950		
Na	11	Na^+ $1s^22s^22p_x^22p_y^22p_z^2$	4560		
Mg	12	Mg^+ $[Ne]3s^1$	1450		
Al	13	Al^+ $[Ne]3s^2$	1820		

Handout Answers:

1. 
   a. n=1 n=2 n=3
   b. 
   c. 
   d.
   e. n=1 and n=∞
   f. IE = $2.179 \cdot 10^{-18}$ J = 13.6eV = 1312 $\frac{\text{kJ}}{\text{mol}}$
   g. IE = $R_y \frac{Z^2}{3^2}$
2.
   a. -15 eV
   b. 6
   c. 15 emissions
   d. -8 eV, 4 loops
   e. -3 eV, 6 loops
   f. No
   g. Yes
   h. Yes
   i. no
   j. $2.4*10^{14}$Hz
   k. (10 lines)
   l. KE=9×10^{-19} J
3. -9Ry
   a. 11.36 nm
4. Yes
5. D,F
6. C
7. No
8. $4d_{zx}$, $4p_y$
   a. The same
9. 0,1,2,3
10. 2s, 4p, 3d
   a. 2s
   b. 0.85 (n_4 to n_∞)

Many Electrons Atoms:

1.
   a. Sulfur
   b. ii, iii, iv
2. a – highest, c – lowest
3. Na^+
4.
   a. [Ar] $4s^2$ $3d^5$
   b. All except C & F
   c. Left column: 1s, 4s, 2p; Right column: 2s, 3s, 3p; Bottom: 3d
   d. ≈30 Å

Additional Practice Problems:

1. E
2. No
3. A, c
4. B, D
5. 6eV
6. $0.94*10^{-19}$ J
7. λ=9$hc/35Ry$
8. $\lambda = \dfrac{100hc}{11Ry}$
9. 3.3eV
10.
   a. 7.5×10^{-20} J
   b. Speed decreases, number will still the same
   c. Speed increases, number of electrons will stay the same
   d. Speed stays the same, number of electrons will increas
13.
   a. 361 nm
   b. 662 nm
   c. 15 lines
   d. 5 lines
14. Z_{eff} = 1.82
15. Na < Li < B < N < Ne
16. $B^+ < N^+ < Ne^+ < Na^+ < Li^+$
17. Al: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$ paramagnetic
    Al^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^0\ 3p^0$diamagnetic
    V: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$ paramagnetic
    V^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^0\ 3d^2$ paramagnetic

Atom	Z	Electron configuration	IE_1 $\frac{kJ}{mol}$	Z_{eff}	Trends in IE_1 is Explained by: e. Z increases f. Electron –electron repulsion g. New shell h. l increases or Z_{eff} decreases (shielding)	Ions (Ions Electron configuration)	IE_2 $\frac{kJ}{mol}$
He	2	$1s^2$	2373	1.35	a	He^+ $1s^1$	**5248**
Li	3	$1s^2 2s^1$	520	1.26	c, d	Li^+ $1s^2$	**7300**
Be	4	$1s^2 2s^2$	**899**	**1.66**	a,b	Be^+ $1s^2 2s^1$	**1757**
B	5	$1s^2 2s^2 2p_x^1$	**801**	**1.56**	d	B^+	2430
C	6	$1s^2 2s^2 2p_x^1 2p_y^1$	1086	1.82	a	C^+ $1s^2 2s^2 2p_x^1$	**2350**
N	7	$1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$	**1400**	**2.07**	a	N^+ $1s^2 2s^2 2p_x^1 2p_y^1$	2860
O	8	$1s^2 2s^2 2p_x^2 2p_y^1 2p_z^1$	**1314**	**2.00**	b	O^+ $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$	**3390**
F	9	$1s^2 2s^2 2p_x^2 2p_y^2 2p_z^1$	1680	2.26	a	F^+	**3370**
Ne	10	$1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2$	2080	2.52	a,b	Ne^+ $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^1$	3950
Na	11	$1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2 3s^1$ $= [Ne]3s^1$	**496**	**1.86**	c, d	Na^+ $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2$	**4560**
Mg	12	$1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2 3s^2$ $= [Ne]3s^2$	738	2.25	a	Mg^+ $[Ne]3s^1$	1450
Al	13	$[Ne]3s^2 3p_x^1$	**578**	**1.99**	d	Al^+ $[Ne]3s^2$	1820

Exam 3 Answers:

1. 4.6kJ
2. 12C(s, graphite) +11H_2(g) +11/2 O_2(g) → $C_{12}H_{22}O_{11}(s)$
3. 6C(s, graphite) +9H_2(g) +3/2 O_2(g) → $CH_3CH_2OH(l)$
4. Cc
   a. -57.05 kJ/mol
   b. 228.2 kJ/mol
   c. -10.86kJ
5. -694 kJ/mol
6. -6 kJ/mol
7.
   a. $1.81*10^{-10}$s
   b. 656nm
   c. -276Kj
8. $q_{\text{sys}} < 0$; $q_{\text{sur}} > 0$; $w < 0$; $\Delta T_{\text{sur}} > 0$; T_{final} (const. pressure) $<$ T_{final} (const. volume)
9. 3,4,2
   0,2,1
   3s,4d,2p
   1,5,3
   B
10. 23.2°C
11. 0J
12. F,F,T,F,F
13. 37.4 kJ/mol