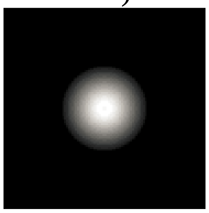
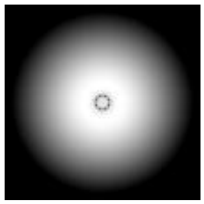
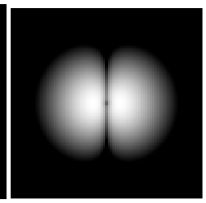
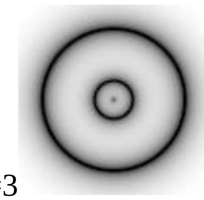
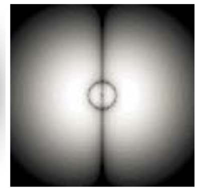
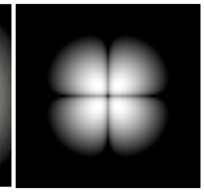
Things you should know when you leave Discussion today for one-electron atoms:

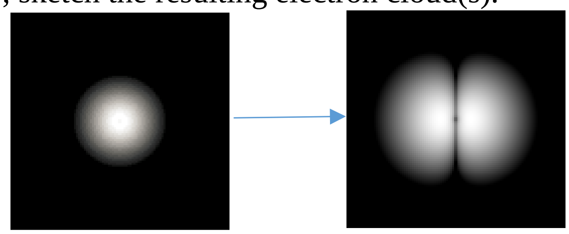
- $\mathbf{E_n = -}R_y\dfrac{Z^2}{n^2}\ \mathbf{= -2.179{\cdot}10^{-18}J}\ \dfrac{Z^2}{n^2}\ \mathbf{= -13.6eV}\ \dfrac{Z^2}{n^2}$
- $\mathbf{\Delta E_{matter}=E_n\text{-}E_m}$ **;** **Ionization Energy=** $\mathbf{E_\infty - E_{n(initial)}}$
- $\mathbf{\Delta E_{light}=h\nu_{light}=}$ **IE +KE**

1. Consider the following energy levels of the hydrogen atom as shown below in the diagram:

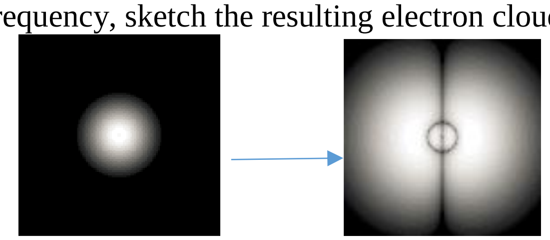
a. Sketch electron clouds corresponding to energy levels up to n=3.(next to the lines on the right →)

n=1 
n=2  
n=3   

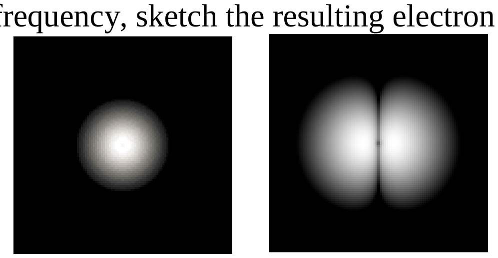
b. When electron cloud of the H atom at the lowest energy interacts with light of the lowest resonate frequency, sketch the resulting electron cloud(s).



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). Only two:



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

n=1 and n=∞

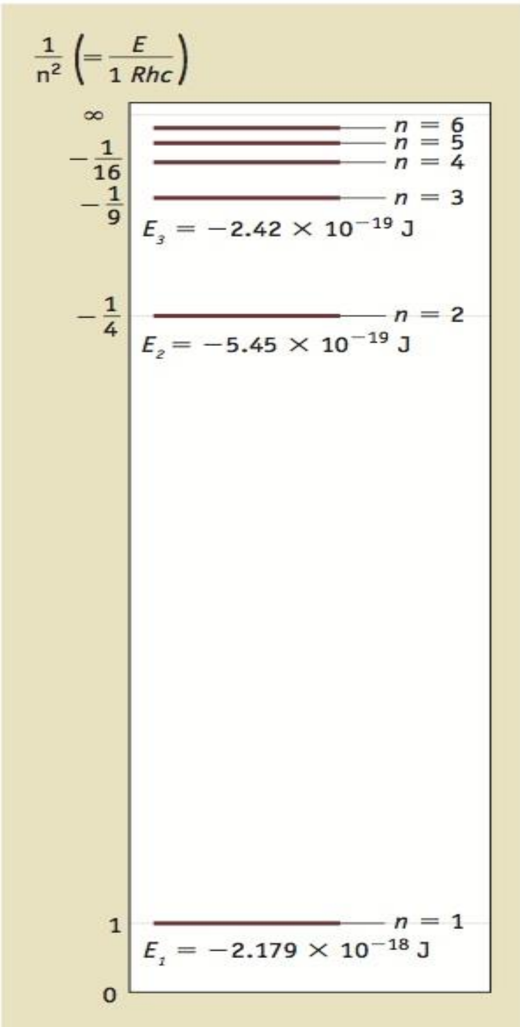
f. What is the ground state H atom ionization energy? (H(*g*) → H^+(*g*) + e^-)

$\mathbf{E_n = -2.179{\cdot}10^{-18}J\ =\ -13.6eV}$

IE= $\mathbf{2.179{\cdot}10^{-18}J\ =\ 13.6eV}$=$1312\left(\dfrac{\text{kJ}}{\text{mol}}\right)$

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

$$\mathbf{IE} = R_y \frac{Z^2}{3^2}$$



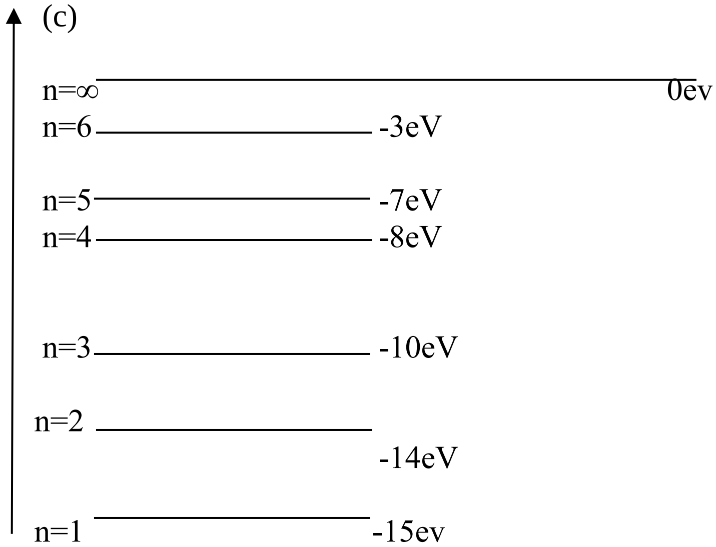
2. An atom, X, has the following **ground state absorption** spectrum (displayed below), and the ground state ionization energy of the atom is 15eV (IE). Each of the **absorption** lines corresponds to a natural frequency of the electron cloud resulting from the mixing of electron wave with 1 loop with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

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

(a) What is the energy of the ground state (of the electron cloud corresponding to one loop) of X? (Careful of a sign!) **–15ev**

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

(c)



(d) Using the energy level diagram you just did draw: How many lines will be present in the electrically-excited emission spectrum of this atom? **At least 15 lines look at any repetitions of the differences.**

(e) What is the energy of the *third excited* state of X? **-8eV** How many loops does that state have?4

(f) What is the energy of the *highest energy state* of X that is necessary to account for the **absorption** spectrum? **-3eV**

(g) 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? **NO**, it will be transparent to it.

(h) Can atom X emit light of energy 3 eV? Yes

(i) Is it possible for X to absorb light of energy 16eV or will it be transparent to it? Why? Yes. The excess energy will be carried away as kinetic energy by the ionized electron.

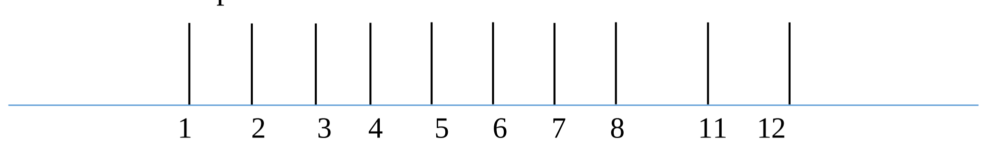
(j) Can atom X emit light of energy16 eV? NO

(k) What is the lowest frequency of the light emitted from the atom?
We need to look for smallest ΔE and it is -1eV;

$$\Delta E = -1\text{eV} = -1.6021766 \times 10^{-19}\text{J} = -h\nu_{light}$$

$$\nu_{light} = \frac{1.6021766 \times 10^{-19}\,\text{J}}{6.6 \times 10^{-34}\,Js} = 2.4 \cdot 10^{14}\text{Hz}$$

(l) Draw the emission spectrum:



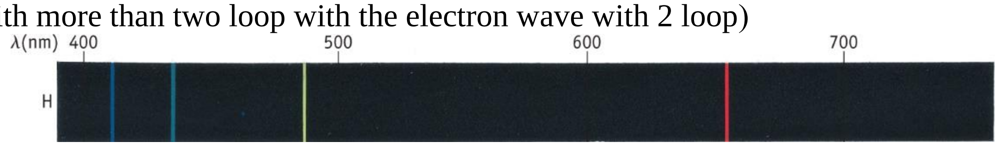
3. What is the expression for the energy in J for the ground state of an electron cloud in Li^{2+}?

$$E_1 = -Ry\frac{Z^2}{n^2} = -9Rhc$$

a. Calculate wavelength (in nm) of the light corresponding to the Li^{2+} electron cloud resulting from mixing a 3 loop electron wave with a1 loop electron wave?

$$\Delta E_{light} + \Delta E_{atom} = 0 \qquad -\frac{hc}{\lambda} = -Ry\left(\frac{Z^2}{n^2_{final}} - \frac{Z^2}{n^2_{initial}}\right) = -Ry\left(\frac{9}{1} - \frac{9}{9}\right); \quad \lambda = 11nm$$

4. 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. <u>The $n = 2$ and $n = 5$ cloud energies</u>
F. None of these.

5. Photons of energy 13.6eV=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? Yes

For He^+ : $E_2 = -13.6eV\,\frac{2^2}{2^2}$ **IE=0 - E_2=13.6Ev**

6. 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. **<u>Atom will be transparent to the light of this wavelength</u>**.
b. Ionization will take place
c. Ionization will not take place
d. The ionized electron will use excess energy for kinetic energy

7. The light with wavelength of 365nm will ionize H atom in the $n = 2$ energy level. What effect will light with wavelength = 265nm have? (Choose all that apply)

a. Atom will be transparent to the light of this wavelength.
b. <u>Ionization will take place</u>
c. Ionization will not take place
d. <u>The ionized electron will use excess energy for kinetic energy</u>

8. 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 %?

$KE = \Delta E_{light} - h\upsilon_0 = h\upsilon_{light} - h\upsilon_0$ changing intensity does not change KE

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 decrase

9. Assume light **is** able to eject electrons from a metal. What do you expect as the wavelength of the light is **increased?** $\frac{hc}{\lambda} - h\upsilon_0 = KE$

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.

10. An electron is ionized from the ground state of an atom, with $E_1 = -1.3 \cdot 10^{-19}$ J, by light with frequency $1.0 \cdot 10^{15}$ Hz. What is the kinetic energy (in eV) of the ejected electron?

$\Delta E_{light} = h\nu = 6.62607004 \cdot 10^{-19}$ J

$IE = -E_1 = 1.3 \cdot 10^{-19}$ J $KE = \Delta E_{light} - IE = 5.326 \cdot 10^{-19}$ J$=3.3$eV

11. The work function (ionization energy), of chromium metal is 7.2×10^{-19} J. What is the maximum kinetic energy of an electron, if it is ejected from chromium metal by light of wavelength 250.nm?

KE= $\mathbf{\Delta E_{light}}$**-IE(Φ)** $= \frac{hc}{\lambda} - 7.2 \cdot 10^{-19} J = 7 \cdot 10^{-20} J$

What will happen to the speed and quantity of the ejected electrons if the wavelength of the light is increased? **Speed will be decrease but number of ejected electrons will be the same**

a. What will happen to the speed and quantity of the ejected electrons if the wavelength of the light is decreased? **Speed will be increase but number of ejected electrons will be the same**

b. What will happen to the speed and quantity of electrons if the intensity of the light is increase? **Speed will be the same but number of ejected electrons will increase**

12. 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)

b. Draw the **emission** spectrum. (Hint: does it always just goes to the ground state?)

0.5ev 1.5ev. 2ev

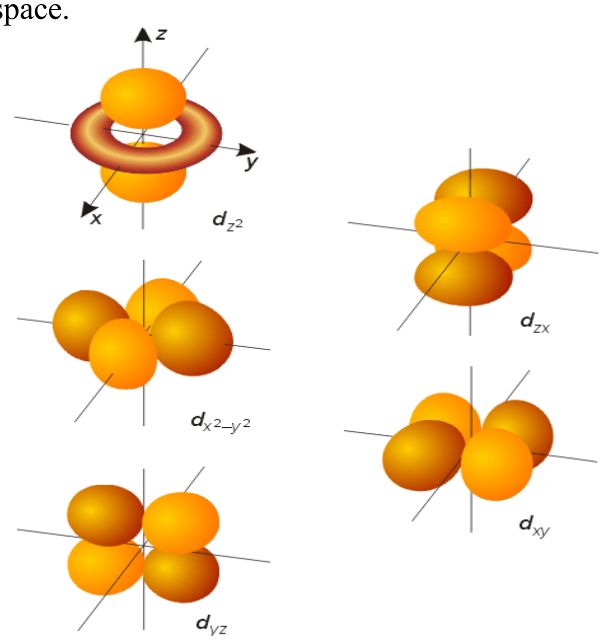
13. One atom emits light of energy 1.27 eV. A second atom has only three energy levels: -0.9 eV, -1.27 eV, and -1.9 eV. Assuming ionization is **not** possible can the second atom **absorb** the light emitted by the first atom? No

Things you should know when you leave Discussion today.

- Atomic wave function family album
    a. Principle quantum number n=1,2,3,… specifies energy level
       $n = j + l$
    b. Number of nodal planes (***l***).
    c. Angular momentum quantum number (l=0, 1, 2,…n-1) defines the shape of the orbital.
    d. $m_l = -l, \ldots 0 \ldots l$
    e. Number of loops **j** (j=n-l)
    f. S, P and D and F orbitals.
    g. Size of the orbital is proportional to n^2
- Electron configuration
    a. Orbital, Shell, Subshell
    b. Shielding
    c. Pauli Exclusion Principle. Auf-bau. Hund's rule
- Periodic Trends (**I.E.**, E.A., Radius, Ionic Radius, Electronegativity)
- For many electron atoms: $E_n = -13.6(\text{eV})\dfrac{Z_{eff}^2}{n^2} = -2.18\cdot10^{-18}(\text{J})\dfrac{Z_{eff}^2}{n^2} = -1312\left(\dfrac{\text{kJ}}{\text{mol}}\right)\dfrac{Z_{eff}^2}{n^2}$

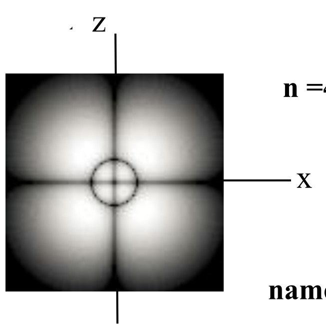
Useful Information

- Below $3d_{xy}$, $3d_{x^2-y^2}$ and $3d_{yz}$ orbital. Be sure to correctly orient your orbitals in the x-y-z space.



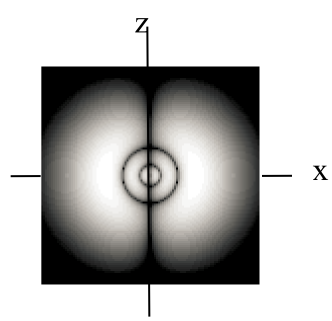
Orbital	*l*	n=j+*l*	j= n-*l*	Shape	Number of orbitals in a subshells(m_l) 2l+1	# e^- that can fit
s	**0**	1 2 3 etc	1 2 3 j=n	Sphere	1 orientation in space	2
p	**1**	2 3 4 etc	1 2 3 j=n-1	Dumbbell	3	6
d	**2**	3 4 etc	1 2 j=n-2	Cloverleaf	5	10
f	**3**	4 5 etc	1 2 j=n-3		**7**	14

2. 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 =4 l= 2 j= 2

name: $4d_{zx}$



n =4 l=1 j=3

name:$4p_x$

a. For the two hydrogen electron clouds above, which has the largest ionization energy? (Note: in H atom, all orbitals of same *n* have the same energy.) **<u>the same</u>**

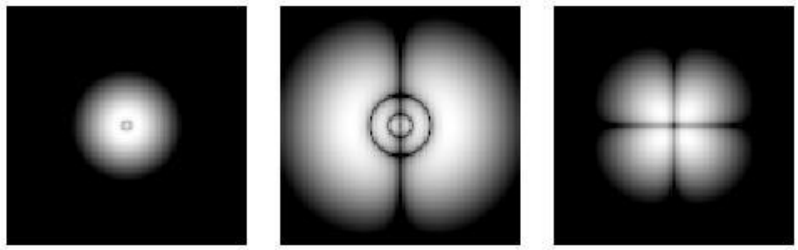
3. What are the possible angular momentum quantum numbers for an orbital in the n=4 shell? 0, 1, 2, 3

- How many **<u>degenerate</u>** orbitals are in the n=3 shell? What are they?(Note: in H atom, all orbitals of same *n* have the same energy.)

4. 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.(Answer: 0.85)



1S 4p 3d

$$IE = E_\infty - E_{initial} = 13.6\frac{Z^2}{n^2} = 13.6eV/16 = 0.85ev$$

Additional Practice problems:

1. 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? **No**

$$\Delta E_{light} = \frac{hc}{\lambda} = 5.5\cdot 10^{-19}$$

$$IE\ (He^+) = 2.18\cdot 10^{-18}(J)\frac{2^2}{1^2} = 8.72\cdot 10^{-18}J$$

2. 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 eV

3. What is kinetic energy of the electron ionized from Li^{2+} in its n = 6 level by light of wavelength 310 nm?(Answer: $0.94*10^{-19}$)

$$KE = \frac{hc}{\lambda} - 2.18\cdot 10^{-18}(J)\frac{3^2}{6^2} = 0.94\cdot 10^{-19}J$$

4. In terms of the variables (like: 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?

$$-\frac{hc}{\lambda_{light}} = -Ry(\frac{Z^2}{n_{final}^2} - \frac{Z^2}{n_{initial}^2}) = -Ry(\frac{4}{1} - \frac{4}{36})\ ;\ \lambda = \frac{9hc}{35Ry}$$

5. 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?

$$-\frac{hc}{\lambda_{light}} = -Ry(\frac{Z^2}{n_{final}^2} - \frac{Z^2}{n_{initial}^2}) = -Ry(\frac{9}{25} - \frac{9}{36})\ ;\ \lambda = \frac{100hc}{11Ry}$$

<u>In preparation for lectures and next week discussion:</u>

6. 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_{∞}-$E_{initial}$ = $2.18 \cdot 10^{-18}(J)\frac{Z_{eff}^2}{n^2}$)

IE (J)= 1086 kJ/mol *10^3/N_A=$181 \cdot 10^{-20}$J ; Z_{eff}=$\sqrt{\frac{IE \cdot n^2}{Rhc}}$ =1.82

Atom	Z	Electron configuration	**IE_1** $\frac{kJ}{mol}$	**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)**	**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

Atom	Z	**Ions (Ions Electron configuration)**	**IE_2** $\frac{kJ}{mol}$	**Z_{eff} For the Ions**	**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^+ $1s^2 2s^1$	**1757**		
B	5	B^+	2430		
C	6	C^+ $1s^2 2s^2 2p_x^1$	**2350**		
N	7	N^+ $1s^2 2s^2 2p_x^1 2p_y^1$	2860		
O	8	O^+ $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$	**3390**		
F	9	F^+	**3370**		
Ne	10	Ne^+ $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^1$	3950		
Na	11	Na^+ $1s^2 2s^2 2p_x^2 2p_y^2 2p_z^2$	**4560**		
Mg	12	Mg^+ $[Ne]3s^1$	1450		
Al	13	Al^+ $[Ne]3s^2$	1820		