From now on, we are going to be thinking about atoms + their reactivities in terms of e-.

- Last week we saw that elements can be grouped based on their chemical reactivity + physical properties. Over the next few lectures, we will be working toward justifying that qualitative observation based on how the electrons are arranged in an atom.

- Lets start our discussion by defining a few terms:

$K_E = \frac{1}{2}mv^2$ Kinetic Energy ≡ energy associated with a moving object

SI unit

$kg\left(\frac{m}{s}\right)^2 = \frac{kg\,m^2}{s^2} = \boxed{\text{Joule}}$

Potential Energy ≡ the energy an object contains due to its position relative to another object

In physics/physical science, we often think about $PE = mgh = kg\frac{m}{s^2}(m)$

This doesn't really work in chemistry; we don't really climb hills

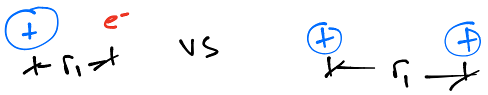
Chemical Potential Energy boils down to a charged particle interacting with another charged particle

$E \propto \frac{q_1 q_2}{r}$ ← You can think of this as an equal sign

q_1 = the charge on the 1st particle

q_2 = the charge on the 2nd particle

r = the distance between these two



$E = \frac{-1(+1)}{r_1} = \ominus$ ← favorable

$E = \frac{(+1)(+1)}{r} = \oplus$ ← not favorable!

Negative energy is a good thing!

Calculate KE of a raindrop (236.0 mg) moving at a speed of 5.4 m s^{-1}
Answer in Joules ($kg\,m^2/s^2$)

$236.0\,mg \cdot \frac{10^{-3}\,g}{1\,mg} \cdot \frac{1\,kg}{10^{3}\,g} = 2.36\times10^{-4}\,kg$

$KE = \frac{1}{2}mv^2 = \frac{1}{2}(2.36\times10^{-4}\,kg)\left(5.4\,\frac{m}{s}\right)^2$

$KE = 3.4\times10^{-3}\,J$

Conservation of Energy → <u>MUST</u> happen

- If a ball is moving w/ 5 J of KE and it comes to a dead stop by hitting a wall, the 5 J of energy (KE now = 0 b/c $v = 0$) must have been transferred to the wall
- this idea will pop up again later w/ the photoelectric effect

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Ok, so we have an Lithium atom that undergoes this reaction:

$Li \rightarrow Li^+ + e^-$ We are forming an ion → this is an ionization process

because that electron is attracted to the (+) nucleus (Potential energy < 0)

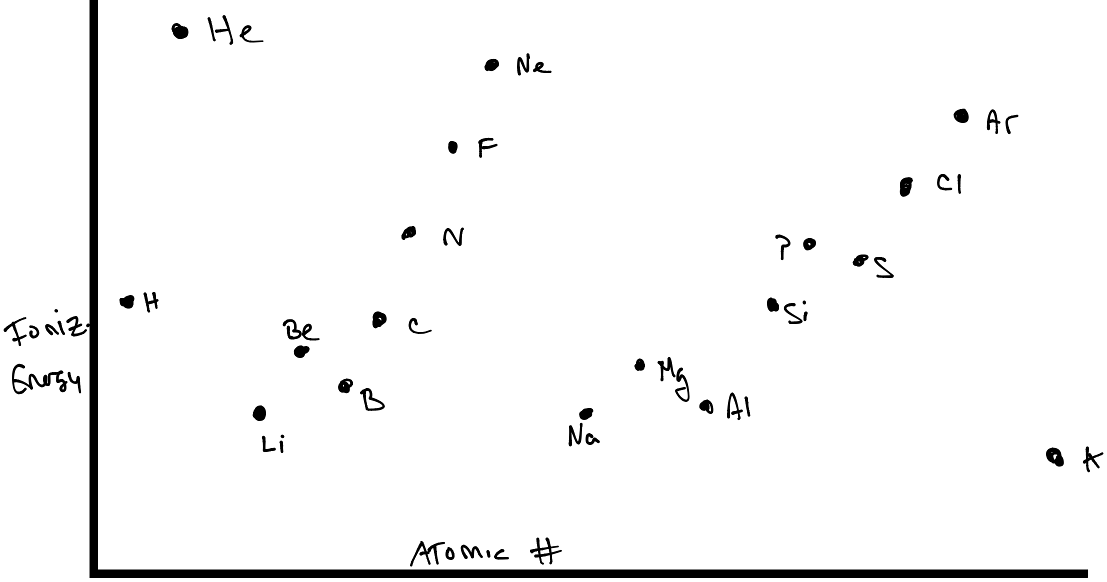
It takes energy to get the electron to separate; It takes energy to make this ionization reaction happen.

This is called an ionization energy → actually the 1st ionization energy

$Li^+ \rightarrow Li^{2+} + e^-$ ⇒ 2nd ionization

$Li^{2+} \rightarrow Li^{3+} + e^-$ ⇒ 3rd ionization

When considering the 1st ionization energies:



He

H vs He

$Z=1$ $\quad$ $Z=2$

$1e^-$ $\quad$ $2e^-$

$\textcircled{+2}$ $\quad e^-$

$$E = \frac{+2(-1)}{r} = \frac{-2}{r}$$

So He is more negative ∴ the e^- is more attracted to the nucleus

H

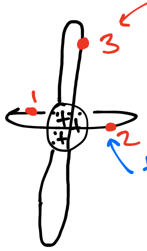
$$E = \frac{(+1)(-1)}{r} = -\frac{1}{r}$$

But Li has +3, so shouldn't $E = -3/r$ be more stable than He (and therefore take more energy to ionize)?

No, because the 3rd electron in Li occupies a new shell!

Roughly speaking, as we move to a new period, an atom gets a new shell!

So Z, still $= +3$, but now r is much bigger for Li than He or H



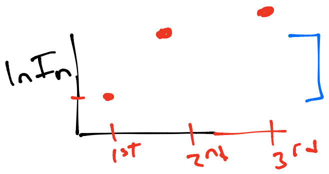
this e^- is weakly bound because its farther away from the nucleus

$Li \rightarrow Li^+ + e^-$ $\quad I_1$

$Li^+ \rightarrow Li^{2+} + e^-$

this e^- is much closer to the nucleus because its in the 1st shell

ln is used b/c the difference in energies is VERY b/c →



big difference b/c going down a shell

So why is the 1st Ionization energy for Be > Li?

Now we're back to the charge of the nucleus: (radii are about equal b/c in the same shell)

Be

$$\frac{+4(-1)}{r} > \frac{+3(-1)}{r}$$

more energy is needed for Be b/c more protons

The 1st two ionization energies for Carbon are 1.81 & 3.90 aJ

How much energy is required to create C^{+2}?

atto = 10^{-18}

$C \rightarrow C^{+} + e^{-}$ 1.81 aJ

$C^{+} \rightarrow C^{2+} + e^{-}$ 3.90 aJ

} added up = 5.71 aJ

Carbon Ionization energies : 1.81 → 3.90 → 7.67 → 10.3 → 62.8 → 78.5

Huge jump b/c going from 2nd shell to 1st shell

It's always the electrons in the outer-most shell that are easiest to ionize

- we give these a special name ⟹ Valence electrons

Core electrons are those in the inner shells

Noble gases are <u>ALWAYS</u> the "end" of a shell (last element in a period)
and we often represent Core e⁻ by putting a noble gas in brackets

[He] = 1st shell core electrons

[Ne] = 1st + 2nd shell

[Ar] = 1st, 2nd + 3rd

Lithium has the Helium core $\boxed{+}$ 1 more

[He]• = Li

We commonly write this as Li•

element symbol

Valence electrons

Now relate # of valence e⁻ back to periodic table

- Each member of a group has the same # of valence electrons
- that is why they have similar chemical and physical properties!

This is known as Lewis Dot representation:
valence e⁻ are always shown ⟹ they are the reactive ones!

If we heat an atom up (give it energy), we can force an electron to be ejected!

this is where stuff gets REALLY cool!

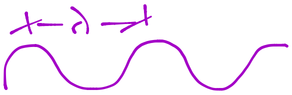
Even though Coulomb's Law can describe some behaviors of electrons interactin with nuclei... it fails to describe ALL observations scientists can make.

This is the basis of the field of quantum mechanics: Electrons have the properties of a wave as they interact with the nucleus of an atom.

Properties of a wave

wavelength $\xrightarrow{(\lambda)}$ this is a length and has a distance unit (m or nm)

frequency → Hz $(1/s)$ ν



ν = how many times a peak of the wave passes by a point in one second

these two are related through the speed of light ($c = 2.9979 \times 10^8 \frac{m}{s}$)

$$\underset{\frac{m}{s}}{c} = \underset{m}{\lambda} * \underset{\frac{1}{s}}{\nu}$$

so if you know the λ, you can easily calculate ν and vice versa

- ν + λ can vary over huge ranges

The energy of any wave can be calculated if you know λ or ν

$$E = h\nu = \frac{hc}{\lambda}$$

h = Planck constant = 6.626×10^{-34} J·s

hugely important!

And as it turns out, energy in this form also has the properties of a particle: Particle Wave Duality

Photon = energy particle (which also has the property of a wave when it is in motion)

Proof that photons can have the properties of a particle:

Photoelectric Effect (think metal in the microwave)

Photons can interact with a surface. If they have enough energy, an e^- will be ejected

same thing as ionization energy!

$$M \longrightarrow M^+ + e^-$$

the electron that is ejected will have a certain amount of kinetic

Sample problem: Calculate KE of ejected e^- when 210 nm light hits a Cu surface

Threshold Energy of copper is $\overbrace{7.1296 \times 10^{-19}\,J}^{\text{energy necessary to eject the } e^-}$

$$E_{photon} = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34}\,J \cdot s\,(2.998 \times 10^{8}\,m/s)}{210 \times 10^{-9}\,m} = 9.459 \times 10^{-19}\,J$$

$$E_{photon} - E_{Cu} = KE = 2.329 \times 10^{-19}\,J$$

Further, we can calculate the velocity of the ejected electron

$$KE = \frac{1}{2} m v^2 \qquad m_{e^-} = 9.109 \times 10^{-31}\,kg$$

$$2.329 \times 10^{-19}\,\frac{kg\,m^2}{s^2} = \frac{9.109 \times 10^{-31}\,kg}{2}\,v^2$$

$$v^2 = 2.556 \times 10^{11}\,\frac{m^2}{s^2}$$

$$v = 5.056 \times 10^{5}\,m/s$$