

# **BERKELEY MATH CIRCLE**

## **The Math of Chemistry: Building Molecules & Their Geometric Shapes Part I**

**Instructor: Patricio Angulo**

# The Periodic Table

Elements are organized into the Periodic Table of Elements. They are organized into columns by their similarities in chemical properties:

**Periodic Table of the Elements**

|                                 |                                 |                                |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   |                                    |                                 |                                      |                                   |                                      |                                     |
|---------------------------------|---------------------------------|--------------------------------|-------------------------------------|---------------------------------|----------------------------------|----------------------------------|---------------------------------|----------------------------------|------------------------------------|-----------------------------------|-----------------------------------|------------------------------------|---------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|-------------------------------------|
| 1<br>IA<br>11A                  |                                 |                                |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   |                                    |                                 |                                      |                                   |                                      | 18<br>VIII A<br>8A                  |
| 1<br>H<br>Hydrogen<br>1.008     |                                 |                                |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   |                                    |                                 |                                      |                                   |                                      | 2<br>He<br>Helium<br>4.003          |
| 3<br>Li<br>Lithium<br>6.941     | 4<br>Be<br>Beryllium<br>9.012   |                                |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   | 5<br>B<br>Boron<br>10.811          | 6<br>C<br>Carbon<br>12.011      | 7<br>N<br>Nitrogen<br>14.007         | 8<br>O<br>Oxygen<br>15.999        | 9<br>F<br>Fluorine<br>18.998         | 10<br>Ne<br>Neon<br>20.180          |
| 11<br>Na<br>Sodium<br>22.990    | 12<br>Mg<br>Magnesium<br>24.305 | 3<br>IIIB<br>3B                | 4<br>IVB<br>4B                      | 5<br>VB<br>5B                   | 6<br>VIB<br>6B                   | 7<br>VIIB<br>7B                  | 8<br>VIII<br>8                  | 9<br>VIII<br>8                   | 10<br>VIII<br>8                    | 11<br>IB<br>1B                    | 12<br>IIB<br>2B                   | 13<br>Al<br>Aluminum<br>26.982     | 14<br>Si<br>Silicon<br>28.086   | 15<br>P<br>Phosphorus<br>30.974      | 16<br>S<br>Sulfur<br>32.066       | 17<br>Cl<br>Chlorine<br>35.453       | 18<br>Ar<br>Argon<br>39.948         |
| 19<br>K<br>Potassium<br>39.098  | 20<br>Ca<br>Calcium<br>40.078   | 21<br>Sc<br>Scandium<br>44.956 | 22<br>Ti<br>Titanium<br>47.88       | 23<br>V<br>Vanadium<br>50.942   | 24<br>Cr<br>Chromium<br>51.996   | 25<br>Mn<br>Manganese<br>54.938  | 26<br>Fe<br>Iron<br>55.933      | 27<br>Co<br>Cobalt<br>58.933     | 28<br>Ni<br>Nickel<br>58.693       | 29<br>Cu<br>Copper<br>63.546      | 30<br>Zn<br>Zinc<br>65.39         | 31<br>Ga<br>Gallium<br>69.732      | 32<br>Ge<br>Germanium<br>72.61  | 33<br>As<br>Arsenic<br>74.922        | 34<br>Se<br>Selenium<br>78.09     | 35<br>Br<br>Bromine<br>79.904        | 36<br>Kr<br>Krypton<br>84.80        |
| 37<br>Rb<br>Rubidium<br>84.468  | 38<br>Sr<br>Strontium<br>87.62  | 39<br>Y<br>Yttrium<br>88.906   | 40<br>Zr<br>Zirconium<br>91.224     | 41<br>Nb<br>Niobium<br>92.906   | 42<br>Mo<br>Molybdenum<br>95.94  | 43<br>Tc<br>Technetium<br>98.907 | 44<br>Ru<br>Ruthenium<br>101.07 | 45<br>Rh<br>Rhodium<br>102.906   | 46<br>Pd<br>Palladium<br>106.42    | 47<br>Ag<br>Silver<br>107.868     | 48<br>Cd<br>Cadmium<br>112.411    | 49<br>In<br>Indium<br>114.818      | 50<br>Sn<br>Tin<br>118.71       | 51<br>Sb<br>Antimony<br>121.760      | 52<br>Te<br>Tellurium<br>127.6    | 53<br>I<br>Iodine<br>126.904         | 54<br>Xe<br>Xenon<br>131.29         |
| 55<br>Cs<br>Cesium<br>132.905   | 56<br>Ba<br>Barium<br>137.327   | 57-71<br>Lanthanide Series     | 72<br>Hf<br>Hafnium<br>178.49       | 73<br>Ta<br>Tantalum<br>180.948 | 74<br>W<br>Tungsten<br>183.85    | 75<br>Re<br>Rhenium<br>186.207   | 76<br>Os<br>Osmium<br>190.23    | 77<br>Ir<br>Iridium<br>192.22    | 78<br>Pt<br>Platinum<br>195.08     | 79<br>Au<br>Gold<br>196.967       | 80<br>Hg<br>Mercury<br>200.59     | 81<br>Tl<br>Thallium<br>204.383    | 82<br>Pb<br>Lead<br>207.2       | 83<br>Bi<br>Bismuth<br>208.980       | 84<br>Po<br>Polonium<br>[208.982] | 85<br>At<br>Astatine<br>209.987      | 86<br>Rn<br>Radon<br>222.018        |
| 87<br>Fr<br>Francium<br>223.020 | 88<br>Ra<br>Radium<br>226.025   | 89-103<br>Actinide Series      | 104<br>Rf<br>Rutherfordium<br>[261] | 105<br>Db<br>Dubnium<br>[262]   | 106<br>Sg<br>Seaborgium<br>[266] | 107<br>Bh<br>Bohrium<br>[264]    | 108<br>Hs<br>Hassium<br>[269]   | 109<br>Mt<br>Meitnerium<br>[268] | 110<br>Ds<br>Darmstadtium<br>[269] | 111<br>Rg<br>Roentgenium<br>[272] | 112<br>Cn<br>Copernicium<br>[277] | 113<br>Uut<br>Ununtrium<br>unknown | 114<br>Fl<br>Flerovium<br>[289] | 115<br>Uup<br>Ununpentium<br>unknown | 116<br>Lv<br>Livermorium<br>[298] | 117<br>Uus<br>Ununseptium<br>unknown | 118<br>Uuo<br>Ununoctium<br>unknown |

|                                  |                                |                                     |                                 |                                   |                                  |                                  |                                  |                                  |                                    |                                  |                                 |                                   |                                  |                                  |
|----------------------------------|--------------------------------|-------------------------------------|---------------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|------------------------------------|----------------------------------|---------------------------------|-----------------------------------|----------------------------------|----------------------------------|
| 57<br>La<br>Lanthanum<br>138.906 | 58<br>Ce<br>Cerium<br>140.115  | 59<br>Pr<br>Praseodymium<br>140.908 | 60<br>Nd<br>Neodymium<br>144.24 | 61<br>Pm<br>Promethium<br>144.913 | 62<br>Sm<br>Samarium<br>150.36   | 63<br>Eu<br>Europium<br>151.966  | 64<br>Gd<br>Gadolinium<br>157.25 | 65<br>Tb<br>Terbium<br>158.925   | 66<br>Dy<br>Dysprosium<br>162.50   | 67<br>Ho<br>Holmium<br>164.930   | 68<br>Er<br>Erbium<br>167.26    | 69<br>Tm<br>Thulium<br>168.934    | 70<br>Yb<br>Ytterbium<br>173.04  | 71<br>Lu<br>Lutetium<br>174.967  |
| 89<br>Ac<br>Actinium<br>227.028  | 90<br>Th<br>Thorium<br>232.038 | 91<br>Pa<br>Protactinium<br>231.036 | 92<br>U<br>Uranium<br>238.029   | 93<br>Np<br>Neptunium<br>237.048  | 94<br>Pu<br>Plutonium<br>244.064 | 95<br>Am<br>Americium<br>243.061 | 96<br>Cm<br>Curium<br>247.070    | 97<br>Bk<br>Berkelium<br>247.070 | 98<br>Cf<br>Californium<br>251.080 | 99<br>Es<br>Einsteinium<br>[254] | 100<br>Fm<br>Fermium<br>257.095 | 101<br>Md<br>Mendelevium<br>258.1 | 102<br>No<br>Nobelium<br>259.101 | 103<br>Lr<br>Lawrencium<br>[262] |

|                 |                   |                     |           |          |                |         |              |            |          |
|-----------------|-------------------|---------------------|-----------|----------|----------------|---------|--------------|------------|----------|
| Alkali<br>Metal | Alkaline<br>Earth | Transition<br>Metal | Semimetal | Nonmetal | Basic<br>Metal | Halogen | Noble<br>Gas | Lanthanide | Actinide |
|-----------------|-------------------|---------------------|-----------|----------|----------------|---------|--------------|------------|----------|

# The Make-Up of Atoms

## Atoms

Atoms are the basic building blocks for all objects in universe, and all elements discovered (or made) are made of different atoms (by elements, I mean “Carbon”, Helium”, Aluminum”, etc.) The atom was originally thought to be smallest particle around, but then, discoveries of sub-atomic particles were made! We have:

1. Proton (+) = **Defines the element!**, positively charged  $+$
2. Electron (-) = negatively charged  $-$
3. Neutron = no charge  $\phi$

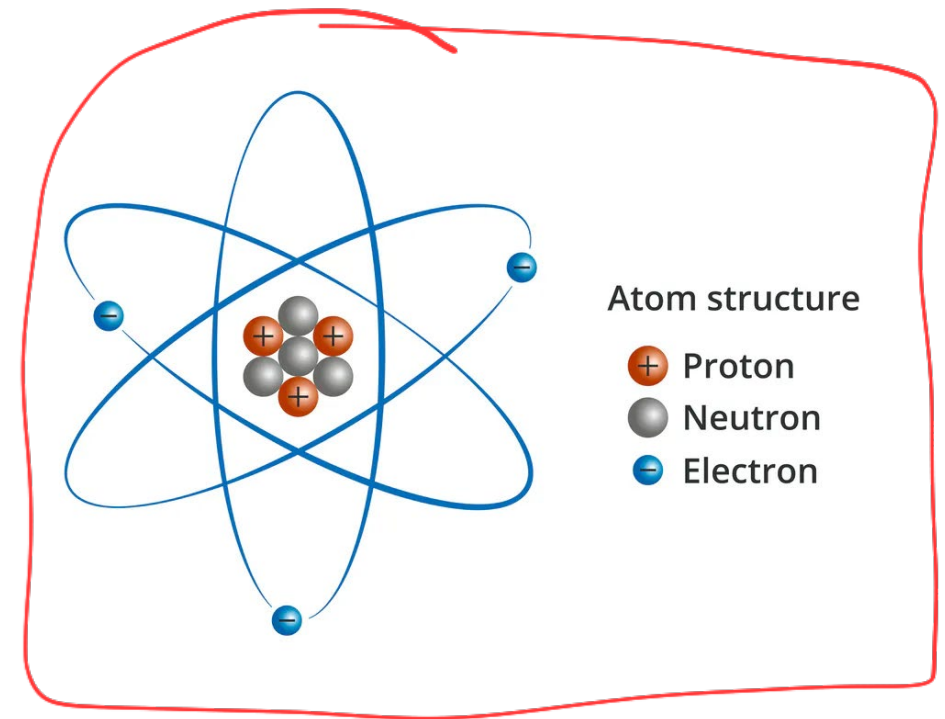
$\hookrightarrow \phi$

## Atom Structure

Protons & Neutrons = exist in nucleus

Electrons = exist outside of the nucleus  $\rightarrow$  **THIS will be our focus!**

~~THIS will be our focus!~~



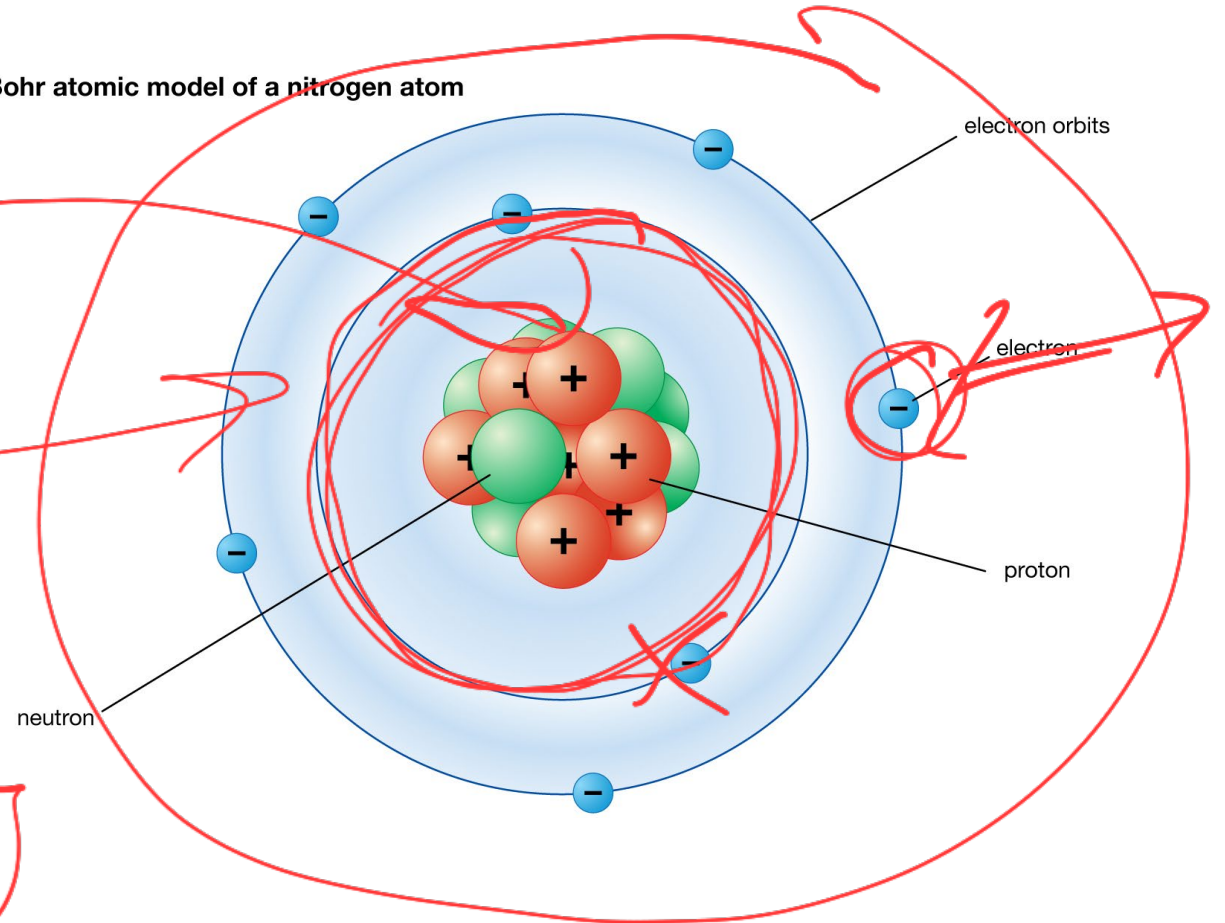
A *old* version of how to *THINK* about this is called the **Bohr Model of Atom**.

It in essence has electrons orbiting around the nucleus, and is still a great way to think about atoms, even though they exist a bit differently in reality.

As with the previous slide:

Protons & Neutrons = exist in nucleus  
Electrons = exist outside of the nucleus

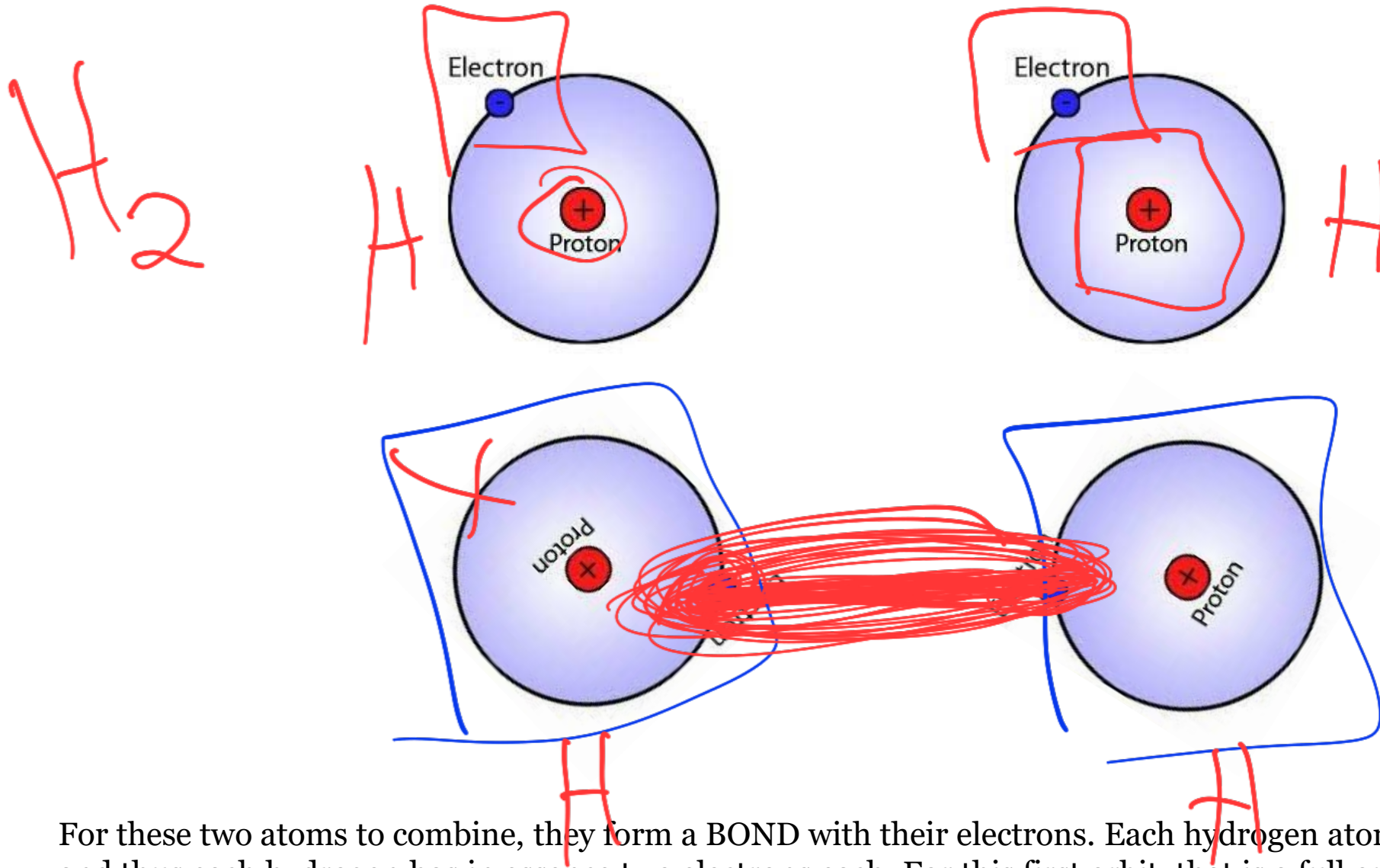
Bohr atomic model of a nitrogen atom



When 2 or more atoms combine, they make molecules!

They do so by **SHARING** electrons from their **outer** most electron orbits! This is referred to as their **valence** shell.

For Example, the molecule  $H_2$  is two hydrogen atoms together. It looks like this:



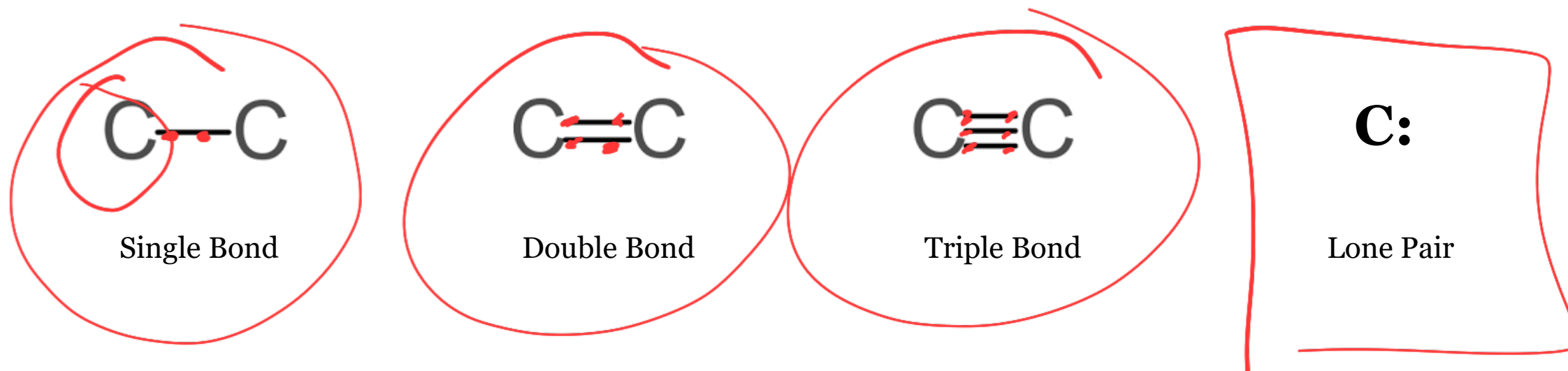
For these two atoms to combine, they form a BOND with their electrons. Each hydrogen atom now shares one electron, and thus each hydrogen has in essence two electrons each. For this first orbit, that is a full orbit, and thus the hydrogen atoms are in a stable state (i.e., they are energetically "happy").

So . . . . .

Here are ground rules for building our molecules from atoms:

1. Hydrogen needs two electrons total to be complete
2. All other atoms we work with will need eight total electrons (we will add some exceptions once we've learned the basics). This is referred to as the OCTET RULE.
3. We will use the Periodic Table to determine how many electrons each atoms has in it's outer orbit, and that will let us know how many it needs to fulfill the Octet Rule (see next slide)
4. Electrons will exist in pairs, either in bonds, or as a pair of electrons (referred to as a lone pair)
5. Bond options can be a single bond (as with hydrogen gas), a double bond (two sets of e's shared) or a triple bond (3 sets of electrons shared).
6. If e's can't be bonded, they may exist as a pair of e's on one atom

So, our options will look like:



Another piece of info before drawing our molecules is how many electrons each atom has in it's outer orbit/shell!

Thankfully, our good friend, The Periodic Table, lets us know that!

**Periodic Table of the Elements**

Handwritten annotations on the periodic table:

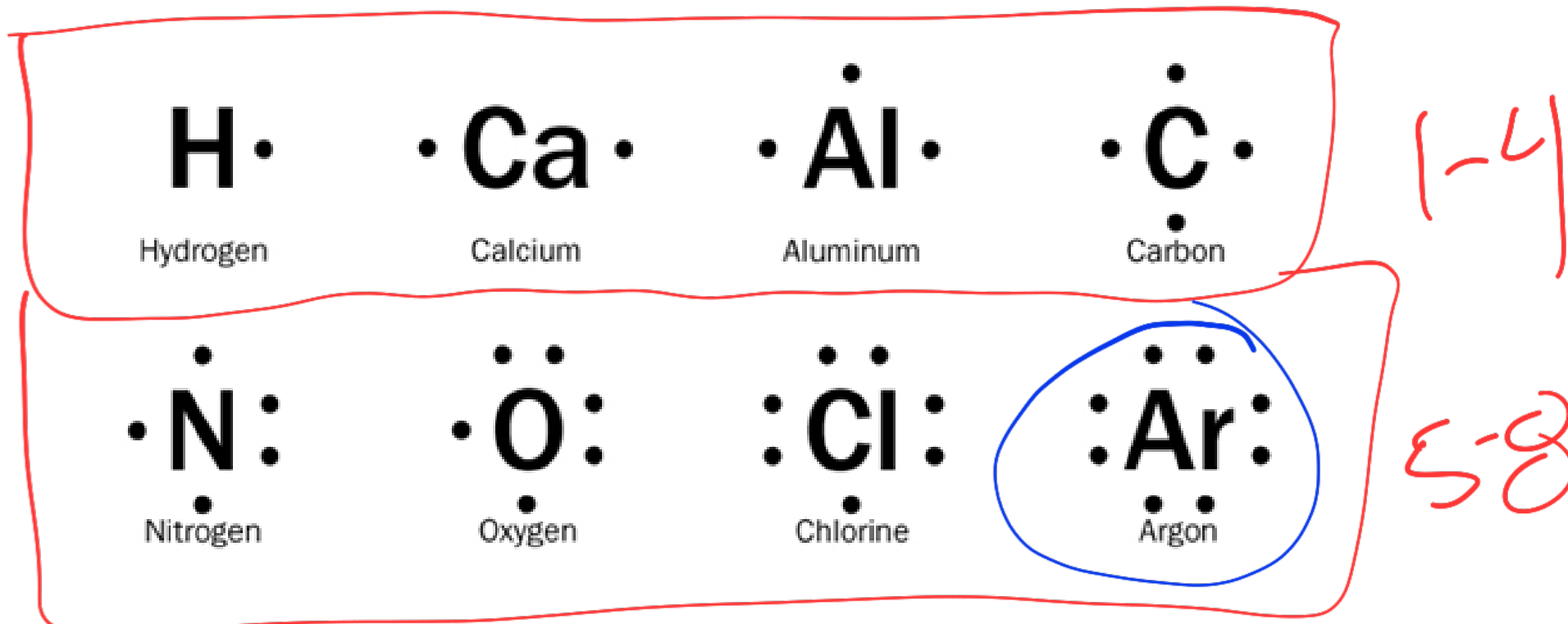
- Number 1 above Group 1 (IA).
- Number 2 above Group 2 (IIA).
- Number 3 above Group 13 (IIIA).
- Number 4 above Group 14 (IVA).
- Number 5 above Group 15 (VA).
- Number 6 above Group 16 (VIA).
- Number 7 above Group 17 (VIIA).
- Number 8 above Group 18 (VIII).

Chemical formulas and arrows:

- $H_2O$  written at the top.
- Red arrows pointing to Phosphorus (P), Chlorine (Cl), and Oxygen (O).
- A red scribble covering the transition metal block (Groups 3-10).

| 1<br>IA<br>11A                  |                                 | 2<br>IIA<br>2A                 |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   |                                    |                                 | 13<br>IIIA<br>3A                     | 14<br>IVA<br>4A                   | 15<br>VA<br>5A                       | 16<br>VIA<br>6A                     | 17<br>VIIA<br>7A           | 18<br>VIII<br>8A |
|---------------------------------|---------------------------------|--------------------------------|-------------------------------------|---------------------------------|----------------------------------|----------------------------------|---------------------------------|----------------------------------|------------------------------------|-----------------------------------|-----------------------------------|------------------------------------|---------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|-------------------------------------|----------------------------|------------------|
| 1<br>H<br>Hydrogen<br>1.008     |                                 |                                |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   |                                    |                                 |                                      |                                   |                                      |                                     | 2<br>He<br>Helium<br>4.003 |                  |
| 3<br>Li<br>Lithium<br>6.941     | 4<br>Be<br>Beryllium<br>9.012   |                                |                                     |                                 |                                  |                                  |                                 |                                  |                                    |                                   |                                   | 5<br>B<br>Boron<br>10.811          | 6<br>C<br>Carbon<br>12.011      | 7<br>N<br>Nitrogen<br>14.007         | 8<br>O<br>Oxygen<br>15.999        | 9<br>F<br>Fluorine<br>18.998         | 10<br>Ne<br>Neon<br>20.180          |                            |                  |
| 11<br>Na<br>Sodium<br>22.990    | 12<br>Mg<br>Magnesium<br>24.305 | 3<br>IIIB<br>3B                | 4<br>IVB<br>4B                      | 5<br>VB<br>5B                   | 6<br>VIB<br>6B                   | 7<br>VIIB<br>7B                  | 8<br>VIII<br>8                  | 9<br>VIII<br>8                   | 10<br>VIII<br>8                    | 11<br>IB<br>1B                    | 12<br>IIB<br>2B                   | 13<br>Al<br>Aluminum<br>26.982     | 14<br>Si<br>Silicon<br>28.086   | 15<br>P<br>Phosphorus<br>30.974      | 16<br>S<br>Sulfur<br>32.066       | 17<br>Cl<br>Chlorine<br>35.453       | 18<br>Ar<br>Argon<br>39.948         |                            |                  |
| 19<br>K<br>Potassium<br>39.098  | 20<br>Ca<br>Calcium<br>40.078   | 21<br>Sc<br>Scandium<br>44.956 | 22<br>Ti<br>Titanium<br>47.88       | 23<br>V<br>Vanadium<br>50.942   | 24<br>Cr<br>Chromium<br>51.996   | 25<br>Mn<br>Manganese<br>54.938  | 26<br>Fe<br>Iron<br>55.933      | 27<br>Co<br>Cobalt<br>58.933     | 28<br>Ni<br>Nickel<br>58.693       | 29<br>Cu<br>Copper<br>63.546      | 30<br>Zn<br>Zinc<br>65.39         | 31<br>Ga<br>Gallium<br>69.732      | 32<br>Ge<br>Germanium<br>72.61  | 33<br>As<br>Arsenic<br>74.922        | 34<br>Se<br>Selenium<br>78.09     | 35<br>Br<br>Bromine<br>79.904        | 36<br>Kr<br>Krypton<br>84.80        |                            |                  |
| 37<br>Rb<br>Rubidium<br>84.468  | 38<br>Sr<br>Strontium<br>87.62  | 39<br>Y<br>Yttrium<br>88.906   | 40<br>Zr<br>Zirconium<br>91.224     | 41<br>Nb<br>Niobium<br>92.906   | 42<br>Mo<br>Molybdenum<br>95.94  | 43<br>Tc<br>Technetium<br>98.907 | 44<br>Ru<br>Ruthenium<br>101.07 | 45<br>Rh<br>Rhodium<br>102.906   | 46<br>Pd<br>Palladium<br>106.42    | 47<br>Ag<br>Silver<br>107.868     | 48<br>Cd<br>Cadmium<br>112.411    | 49<br>In<br>Indium<br>114.818      | 50<br>Sn<br>Tin<br>118.71       | 51<br>Sb<br>Antimony<br>121.760      | 52<br>Te<br>Tellurium<br>127.6    | 53<br>I<br>Iodine<br>126.904         | 54<br>Xe<br>Xenon<br>131.29         |                            |                  |
| 55<br>Cs<br>Cesium<br>132.905   | 56<br>Ba<br>Barium<br>137.327   | 57-71                          | 72<br>Hf<br>Hafnium<br>178.49       | 73<br>Ta<br>Tantalum<br>180.948 | 74<br>W<br>Tungsten<br>183.85    | 75<br>Re<br>Rhenium<br>186.207   | 76<br>Os<br>Osmium<br>190.23    | 77<br>Ir<br>Iridium<br>192.22    | 78<br>Pt<br>Platinum<br>195.08     | 79<br>Au<br>Gold<br>196.967       | 80<br>Hg<br>Mercury<br>200.59     | 81<br>Tl<br>Thallium<br>204.383    | 82<br>Pb<br>Lead<br>207.2       | 83<br>Bi<br>Bismuth<br>208.980       | 84<br>Po<br>Polonium<br>[208.982] | 85<br>At<br>Astatine<br>209.987      | 86<br>Rn<br>Radon<br>222.018        |                            |                  |
| 87<br>Fr<br>Francium<br>223.020 | 88<br>Ra<br>Radium<br>226.025   | 89-103                         | 104<br>Rf<br>Rutherfordium<br>[261] | 105<br>Db<br>Dubnium<br>[262]   | 106<br>Sg<br>Seaborgium<br>[266] | 107<br>Bh<br>Bohrium<br>[264]    | 108<br>Hs<br>Hassium<br>[269]   | 109<br>Mt<br>Meitnerium<br>[268] | 110<br>Ds<br>Darmstadtium<br>[269] | 111<br>Rg<br>Roentgenium<br>[272] | 112<br>Cn<br>Copernicium<br>[277] | 113<br>Uut<br>Ununtrium<br>unknown | 114<br>Fl<br>Flerovium<br>[289] | 115<br>Uup<br>Ununpentium<br>unknown | 116<br>Lv<br>Livermorium<br>[298] | 117<br>Uus<br>Ununseptium<br>unknown | 118<br>Uuo<br>Ununoctium<br>unknown |                            |                  |

The LAST piece of info we need is how to start our drawings with these electrons represented, so that we can then connect everything. Using our 1-8 columns on the previous slide, we draw the electrons around our atom symbol like below. This is referred to as “Lewis Dot Diagrams”. When connected as molecules, we refer to them as “Lewis Dot Structures”.





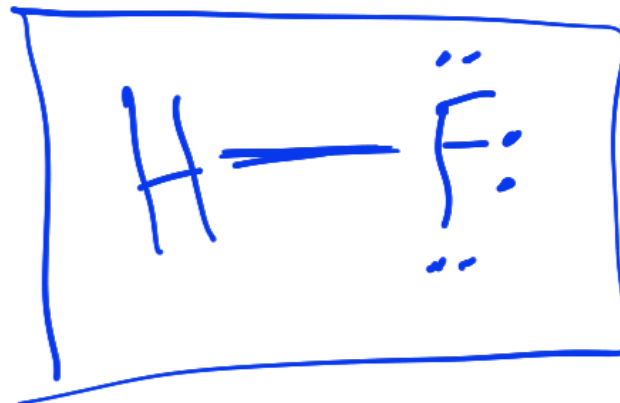
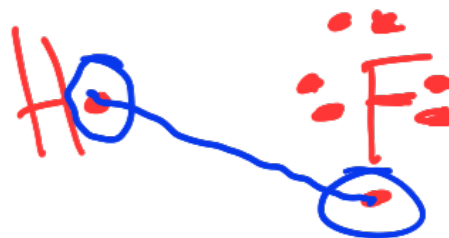
So, let's review all pieces of our drawing puzzle so we may begin:

| Ground Rules   | Number of Electrons Drawn  | Dot Diagrams  |
|--|--|---|
| <ul style="list-style-type: none"><li>• Octet Rule (except Hydrogen)</li><li>• Single Bonds</li><li>• Double Bonds</li><li>• Triple Bonds</li><li>• Lone Pairs</li></ul> | <ul style="list-style-type: none"><li>• Obtained from the Periodic Table</li><li>• Column's 1-8 = # of e's</li></ul> | <ul style="list-style-type: none"><li>• Four sides to our atom symbol</li><li>• One dot per side first</li><li>• After, electrons can be paired</li></ul> |

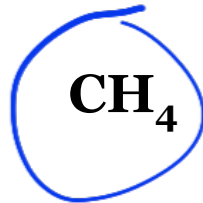
For example:

**HF**

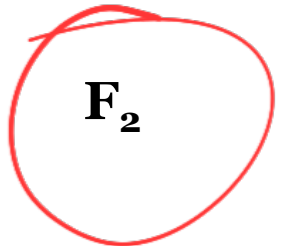
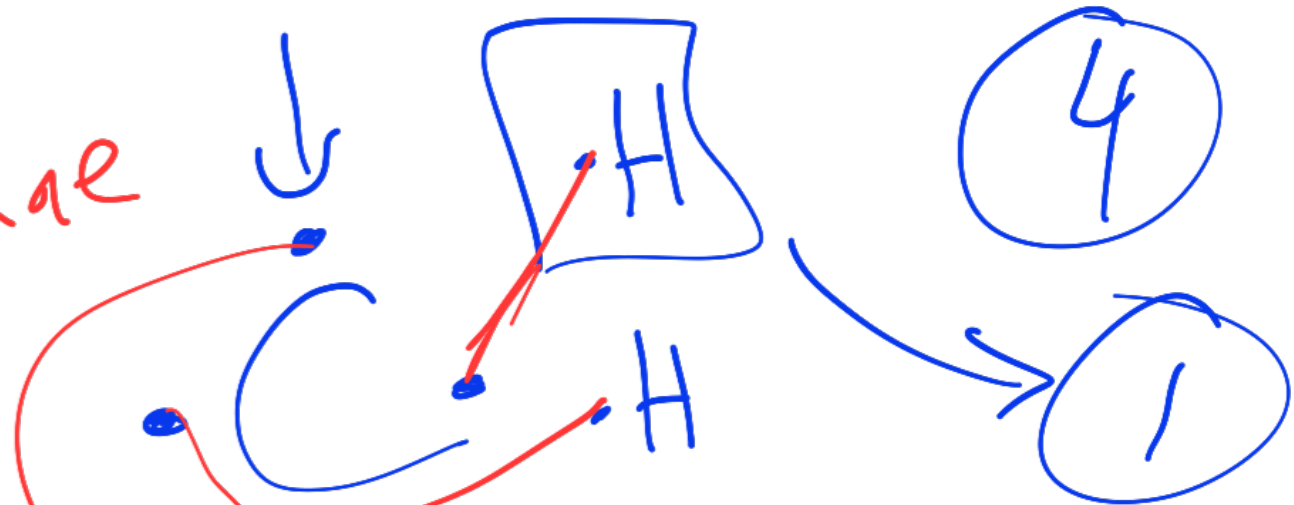
H = 1<sup>st</sup> Column  
F = 7<sup>th</sup> Column



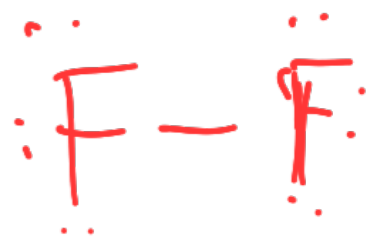
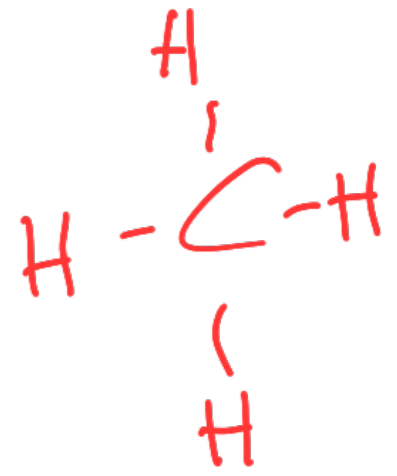
Let's have fun drawing!



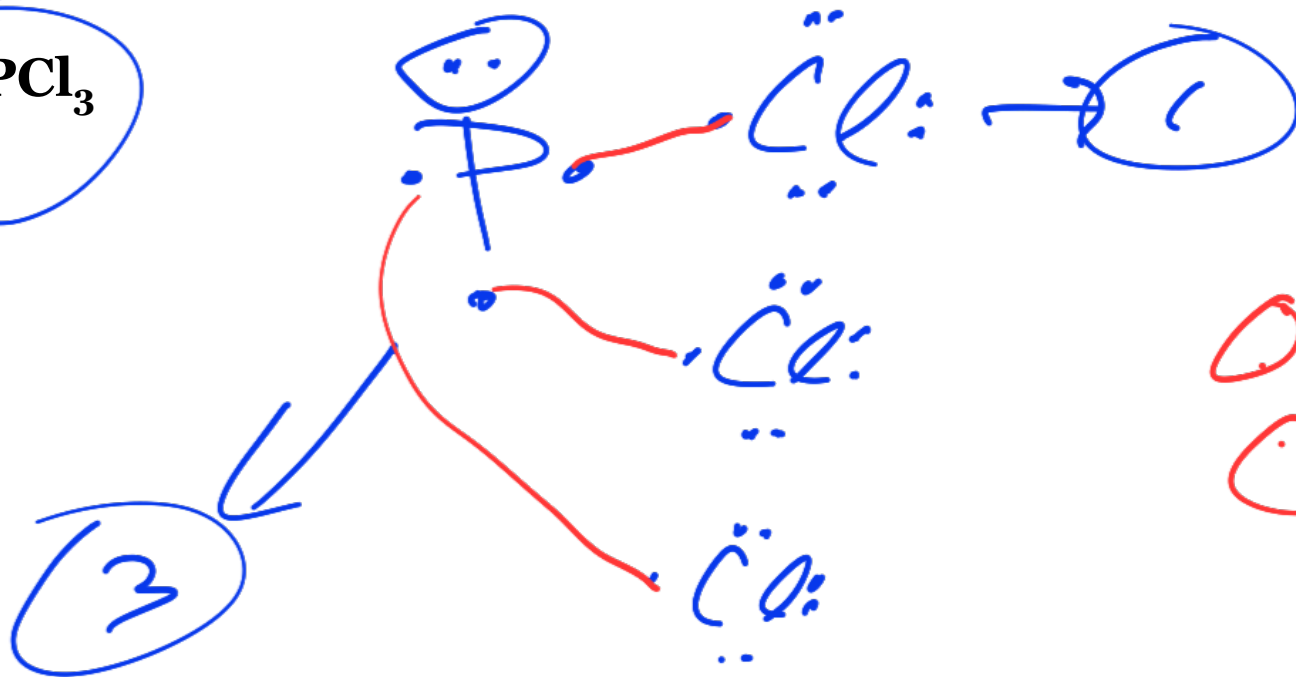
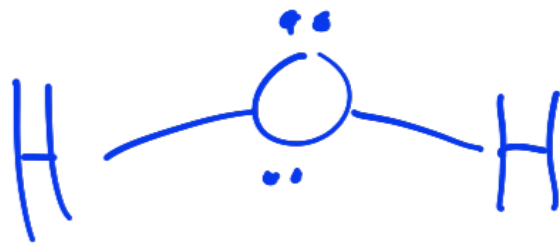
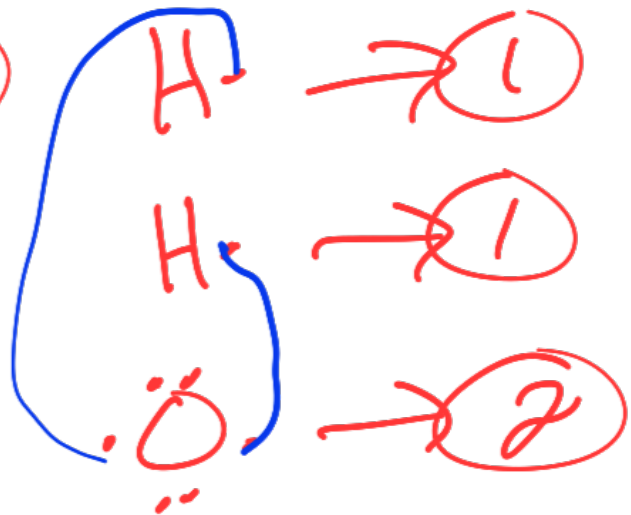
Methane



Fluorine Gas

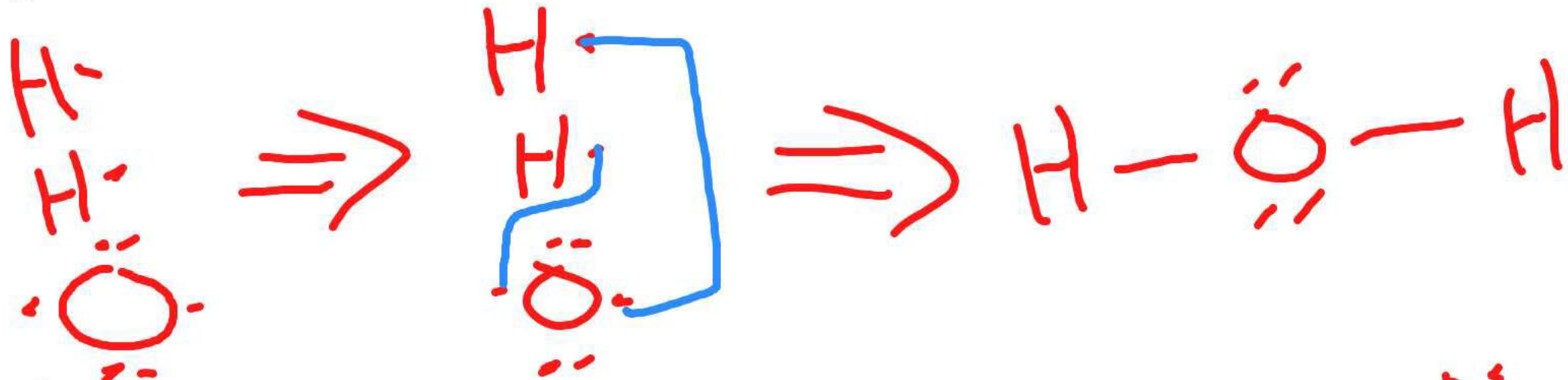


Let's have fun drawing!



Let's have fun drawing!

**H<sub>2</sub>O**



**PCl<sub>3</sub>**

