DESCRIBING CHEMICAL BONDING

"octet rule"

- a "rule of thumb" (NOT a scienfitic law) predicting how atoms will exchange or share electrons to form chemical compounds

- atoms will gain, lose, or share enough electrons so that they end up with full "s" and "p" subshells in their outermost shell.

  - Why "octet"? An "s" subshell can hold two electrons, while a "p" subshell can hold six. 2+6 = 8

IONIC COMPOUNDS

- When atoms react to form IONS, they GAIN or LOSE enough electrons to end up with full "s" and "p" subshells.

example: $Al + 3\,Br \rightarrow AlBr_3$

Al: $[Ne]3s^2 3p^1$

Br: $[Ar]3d^{10}4s^2 4p^5$

Br: $[Ar]3d^{10}4s^2 4p^5$

Br: $[Ar]3d^{10}4s^2 4p^5$

Al^{3+}: $[Ne]$ ($1s^2 2s^2 2p^6$)

Br^-: $[Ar]3d^{10}4s^2 4p^6$

Br^-: $[Ar]3d^{10}4s^2 4p^6$

Br^-: $[Ar]3d^{10}4s^2 4p^6$

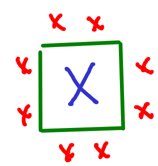
Aluminum loses its outer three electrons, and each bromine gains one!

... but using electron configurations to describe how aluminum bromide forms is a bit cumbersome! Can we simplify the picture a bit?

LEWIS NOTATION / ELECTRON-DOT NOTATION

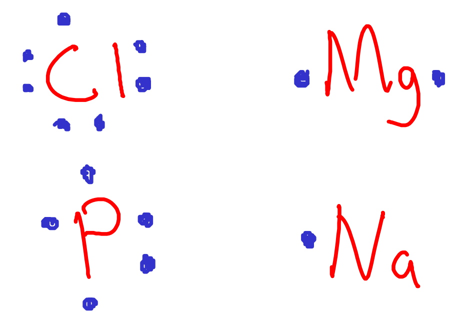
- Lewis notation represents each VALENCE electron with a DOT drawn around the atomic symbol. Since the valence shell of an atom contains only "s" and "p" electrons, the maximum number of dots drawn will be EIGHT.

- To use electron-dot notation, put a dot for each valence electron around the atomic symbol. Put one dot on each "side" of the symbol (4 sides), then pair the dots for atoms that have more than four valence electrons.



examples:

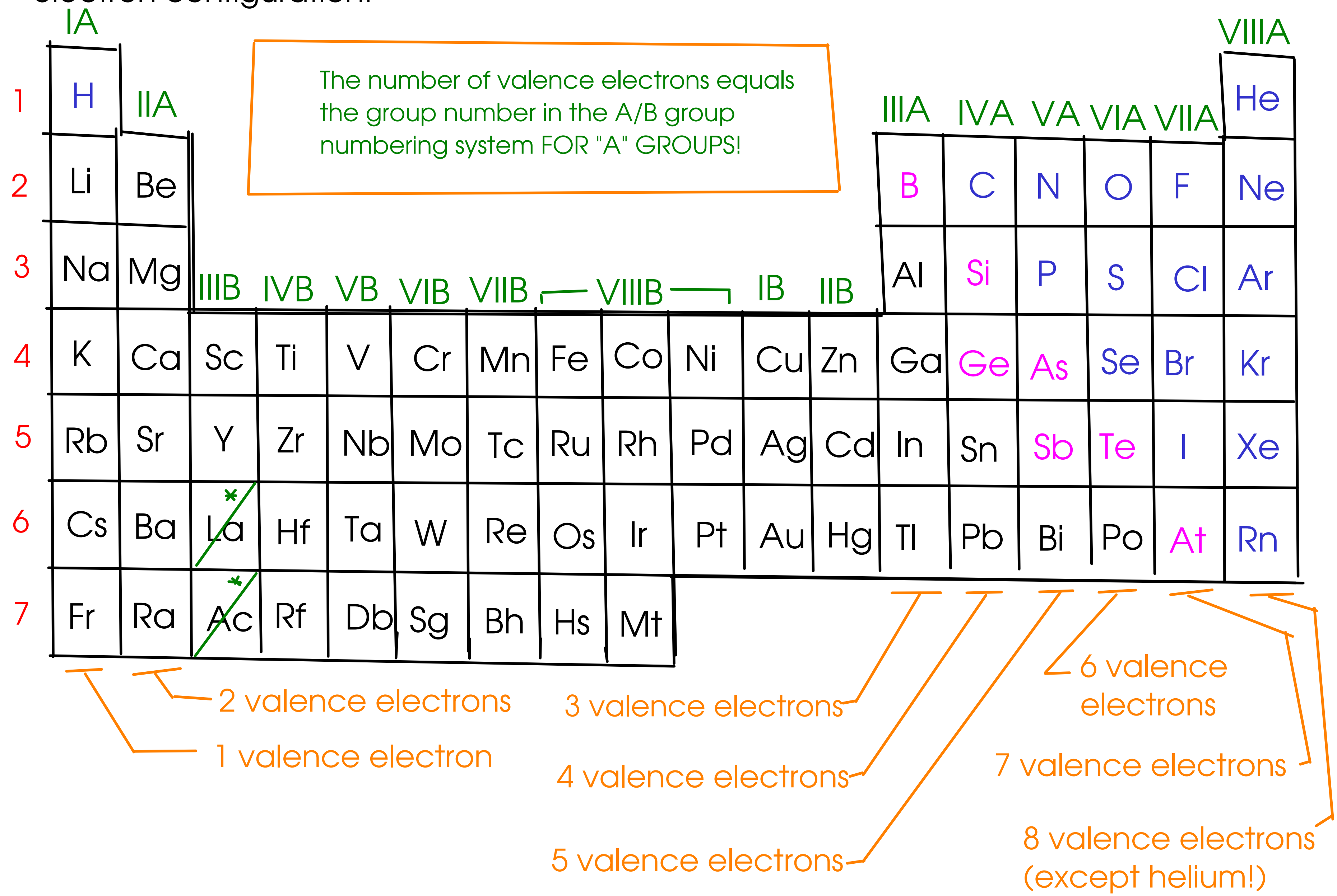
More examples



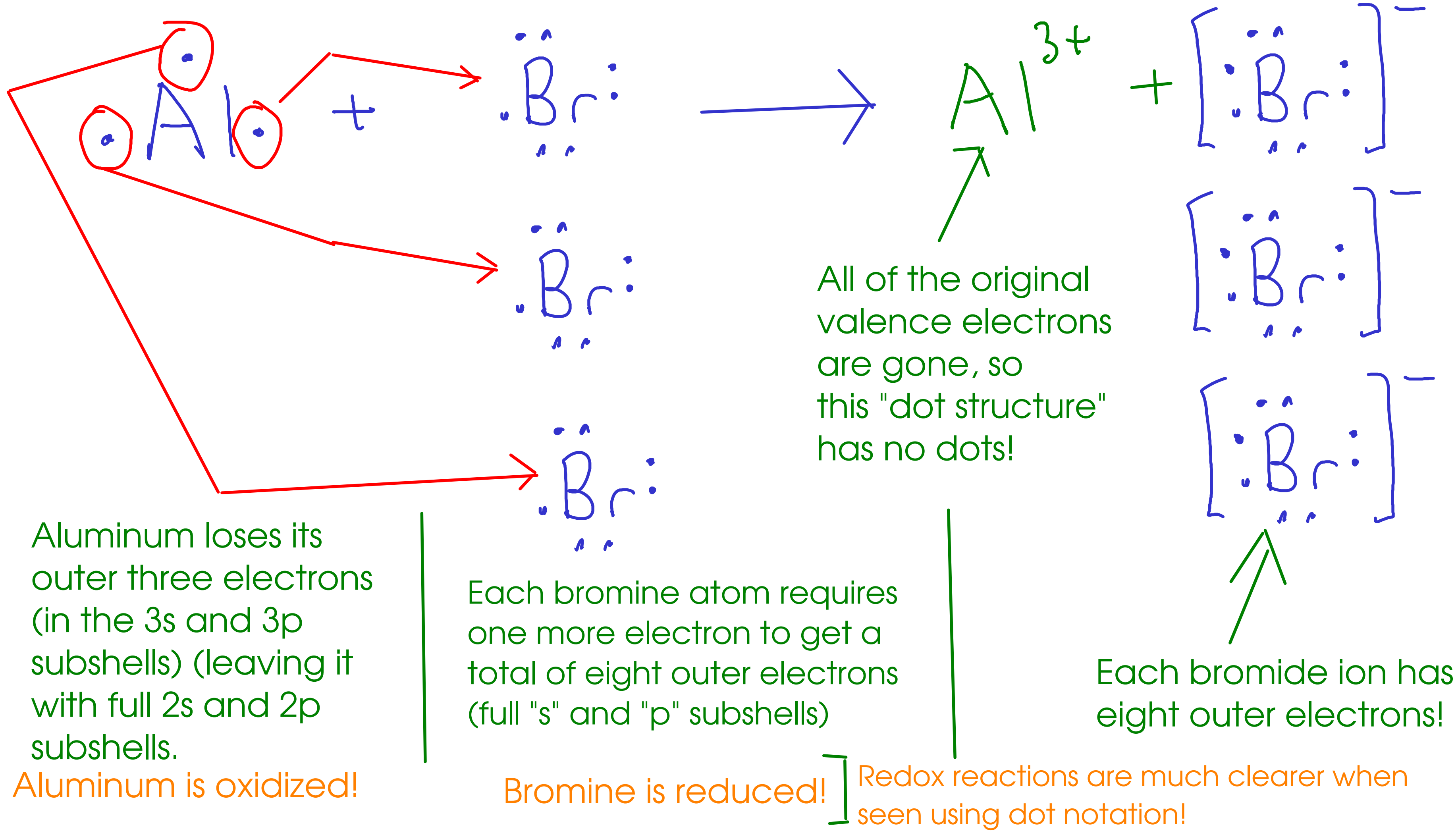
Which "side" you draw the dots on isn't important, as long as you have the right number of electrons and the right number of "pairs"

. . . are all equivalent!

To draw a dot structure for an atom, you need to know HOW MANY valence electrons it has! You can determine this simply from the periodic table, WITHOUT writing the whole electron configuration!



... but how do we use this to describe a reaction that produces ions? Let's look at our previous example!



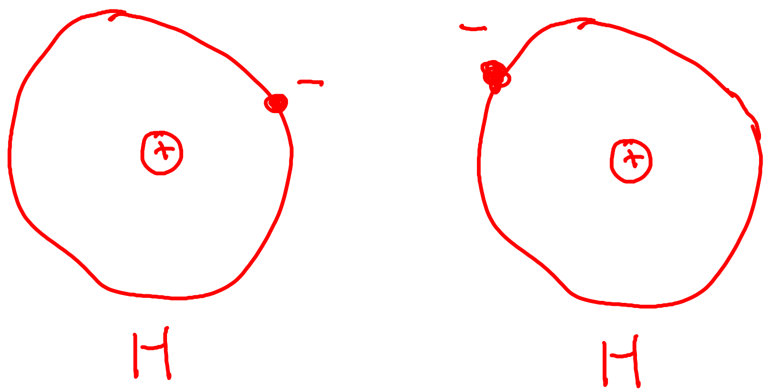
... this is a bit easier to follow than looking at all those letters and numbers in the electron configurations for these elements!

MOLECULAR COMPOUNDS

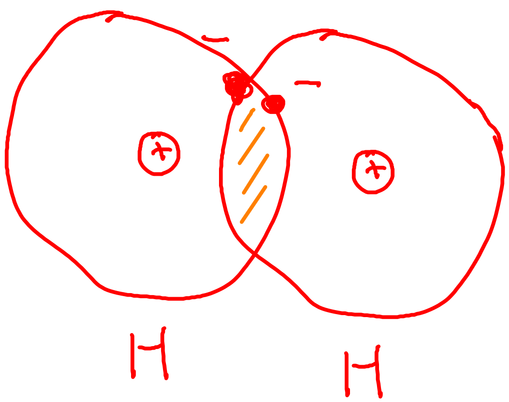
- Form when atoms SHARE electrons instead of transferring them. This results in the formation of MOLECULES ... groups of atoms held together by electron-sharing.

How might atoms SHARE electrons? By coming together close enough so that their atomic ORBITALS overlap each other:

This idea is called VALENCE BOND THEORY!



Each hydrogen atom has a single electron in a 1s orbital.

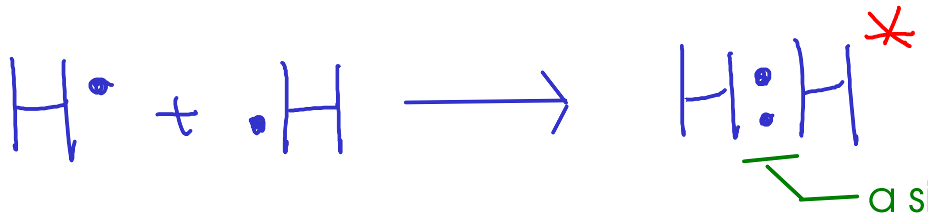


When hydrogen atoms come close enough to each other for these orbitals to OVERLAP, each hydrogen "sees" BOTH electrons, filling up the "s" orbitals of both atoms. This is a COVALENT BOND.

Co: together
Valent: valence shells

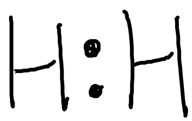
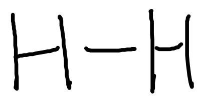
This is the DIATOMIC MOLECULE, H_2

... so how would this look using dot notation?



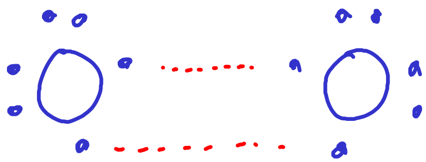
a single shared pair of electrons.
This is called a SINGLE BOND

In dot structures, SHARED PAIRS of electrons are often written as DASHES to make the structures look neater.

 becomes 

* Why doesn't hydrogen end up with eight electrons? Because hydrogen has only the first shell, which contains only a single "s" subshell (NO "p" subshell). This "s" subshell is full with two electrons, and that's all hydrogen needs to get.

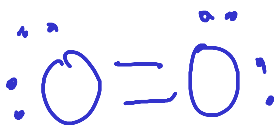
Let's look at OXYGEN ...



We know that oxygen exists in air as the diatomic molecule O_2

The oxygen atoms share TWO pairs of electrons. This is called a DOUBLE BOND

OR



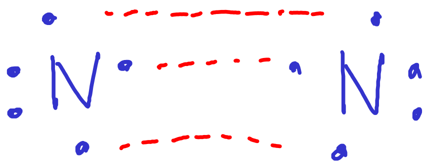
Each oxygen atom has a share in eight electrons!

A few notes on the double bond:

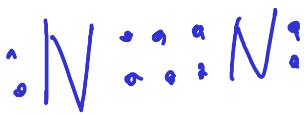
(1) - For atoms to share more than one pair of electrons, they have to move closer to one another than they would if they were only sharing one pair of electrons. This BOND DISTANCE is measurable!

(2) - It takes more energy to break a double bond between two atoms than it would to break a single bond between the same two atoms. This BOND ENERGY is also measurable!

Let's look at NITROGEN ...

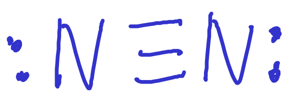


We know that nitrogen exists in air as the diatomic molecule N_2



The nitrogen atoms share THREE pairs of electrons. This is called a TRIPLE BOND

OR



Nitrogen gas is fairly inert ... it's hard to break the triple bond in nitrogen gas apart!

A few notes on the triple bond:

(1) - For atoms to share three pairs of electrons, they have to move closer to one another than they would if they were sharing one or two pairs of electrons. Triple bonds have the shortest BOND DISTANCE of all covalent bonds.

(2) - It takes more energy to break a triple bond between two atoms than it would to break either a single or double bond between the same two atoms. The triple bond has the largest BOND ENERGY of all three kinds of covalent bonds.

SO FAR, we've seen that ...

(1) Atoms may share one, two, or three pairs of electrons with each other.

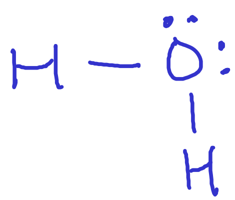
(2) Atoms will usually share enough electrons so that each atom ends up with a share in EIGHT electrons - the "octet rule"

- HYDROGEN will only end up with two electrons!
- Some other atoms may end up with more or less than eight electrons. Exceptions to the octet rule are covered in Chapter 9.

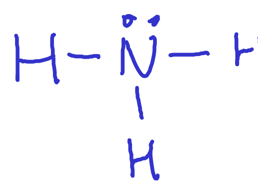
NOW, how could we come up with dot structures for some more complicated (and therefore, more interesting) molecules?

Examples:

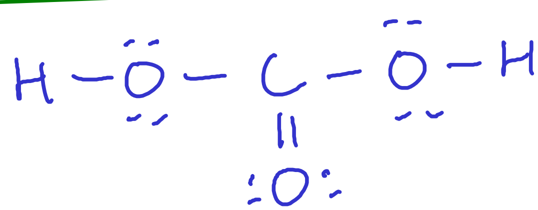
H_2O



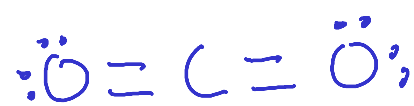
NH_3



H_2CO_3



CO_2



DRAWING DOT STRUCTURES FOR SIMPLE MOLECULES

(1) Count valence electrons

(2) Pick central atom and draw skeletal structure

- central atom is usually the one that needs to gain the most electrons!
- skeletal structure has all atoms connected to center with single bonds

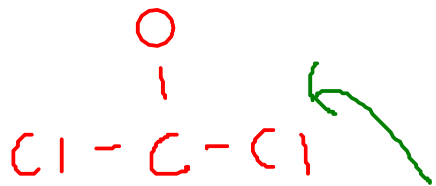
(3) Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

(4) Check octet rule - each atom should have a share in 8 electrons (H gets 2). if not, make double or triple bonds.

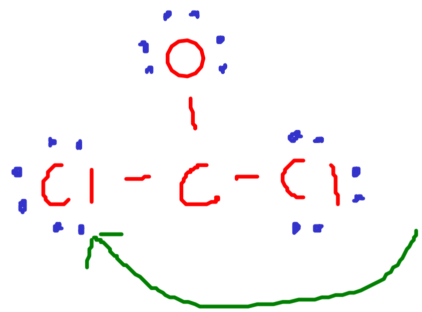
$COCl_2$

C : 1x4
O : 1x6
Cl : 2x7 = 14

24 electrons

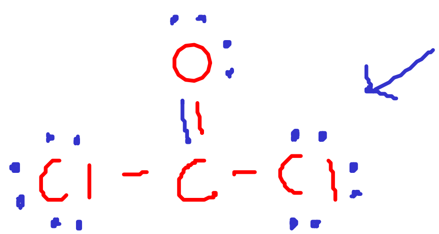


Choose CARBON as the central atom, since it needs to gain more electrons (4) than either chlorine or oxygen.



Distribute remaining electrons. Stop when we run out (24 total)

... but the central carbon atom only has a share in SIX valence electrons! How to fix? We make a DOUBLE BOND ... but with which atom? We'll choose OXYGEN, as it needed to gain two more electrons to begin with - and the atom will gain an additional electron with each bond formed!



This structure has each atom with eight valence electrons!

1. Count valence electrons

2. Pick central atom and draw skeletal structure
   - central atom is usually the one that needs to gain the most electrons!
   - skeletal structure has all atoms connected to center with single bonds

3. Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

4. Check octet rule - each atom should have a share in 8 electrons (H gets 2). if not, make double or triple bonds.

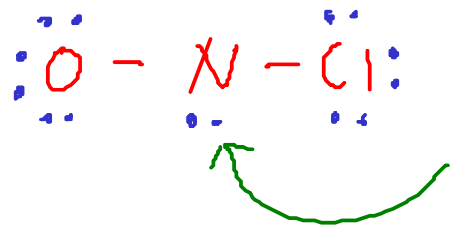
NOCl

N : 1 x 5
O : 1 x 6
Cl : 1 x 7

18 e^-

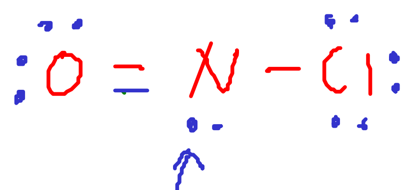
O – N – Cl

We pick NITROGEN as the central atom, since it needs to gain three valence electrons (more than O or Cl)



We ran out of space on the outer atoms, so the last pair goes on the central N atom.

Even with the pair added to N, N still has only six valence electrons. So we need a double bond. Choose OXYGEN, for the same reason as last time!



Now all the atoms have a share in eight valence electrons!

(1) Count valence electrons

(2) Pick central atom and draw skeletal structure

- central atom is usually the one that needs to gain the most electrons!
- skeletal structure has all atoms connected to center with single bonds

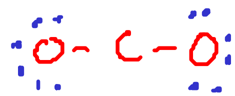
(3) Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

(4) Check octet rule - each atom should have a share in 8 electrons (H gets 2). if not, make double or triple bonds.

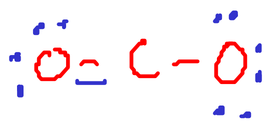
CO_2

C: 1 x 4
O: 2 x 6

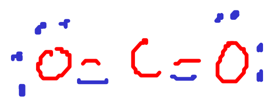
$16 e^-$



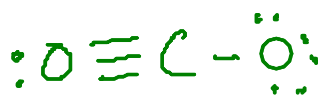
... but the carbon atom only has a share in FOUR outer electrons!



... and now six ...



Adding a second double bond gives carbon a share in eight valence electrons!



The two oxygen atoms are in identical environments and should bond the same way!

This structure also says that one oxygen atom is closer to the central carbon than the other, since triple bonds and single bonds have different BOND DISTANCES.

Experimentally (x-ray diffraction), this isn't true. There's one bond distance - consistent with the double bond structure!

200

(1) Count valence electrons

(2) Pick central atom and draw skeletal structure

- central atom is usually the one that needs to gain the most electrons!
- skeletal structure has all atoms connected to center with single bonds

(3) Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

(4) Check octet rule - each atom should have a share in 8 electrons (H gets 2). if not, make double or triple bonds.

HNO_2 "nitrous acid"

In oxyacids, the acidic hydrogen atoms are attached to OXYGEN atoms in the structure!

H: 1 x 1
N: 1 x 5
O: 2 x 6

18 e^-

O - N - O - H

OXYACID, so we attach the H to O instead of to N ...

... but NITROGEN has a share in only six valence electrons!

Unlike the carbon dioxide molecule, the nitrous acid molecule has two oxygen atoms in DIFFERENT environment.

A DOT STRUCTURE FOR A LARGER MOLECULE

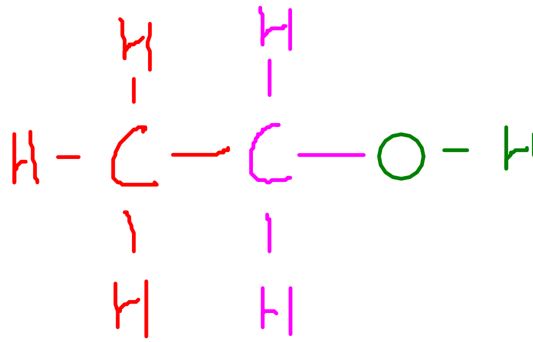
CH_3CH_2OH ETHANOL!

C : 4 x 2 = 8
H : 1 x 6 = 6
O : 6 x 1 = 6
| 20

This formula gives us a hint to the structure of ethanol. Ethanol has THREE central atoms chained together.

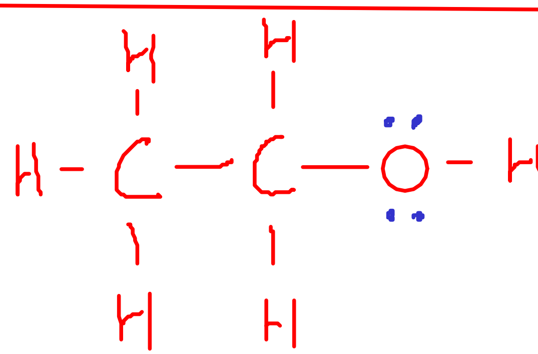
1. Count valence electrons

2. Pick central atom and draw skeletal structure
   - central atom is usually the one that needs to gain the most electrons!
   - skeletal structure has all atoms connected to center with single bonds



CH_3 CH_2 OH

3. Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.



4. Check octet rule - each atom should have a share in 8 electrons (H gets 2). if not, make double or triple bonds.

A DOT STRUCTURE FOR A POLYATOMIC ION

(1) Count valence electrons

(2) Pick central atom and draw skeletal structure

- central atom is usually the one that needs to gain the most electrons!
- skeletal structure has all atoms connected to center with single bonds

(3) Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

(4) Check octet rule - each atom should have a share in 8 electrons (H gets 2). if not, make double or triple bonds.

NH_4^+

N: 1 x 5
H: 4 x 1

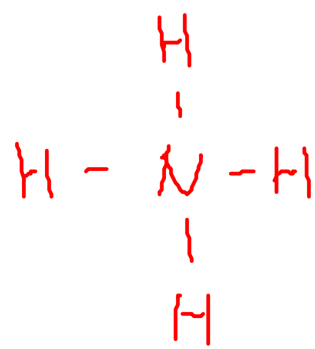
$9e^-$

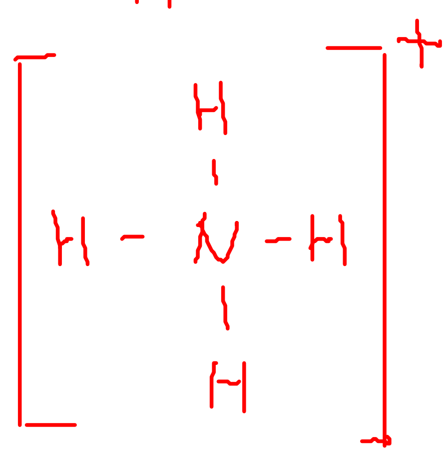
$-1e^-$

$8e$

Wait ... An ODD number of electrons? The molecular dot structures we've seen so far have all been even numbers.

Subtract one electron to account for the +1 charge. (If this were an anion, we'd add the appropriate number of electrons!)





For an ion, draw brackets around the structure and put the charge in the upper right-hand corner.