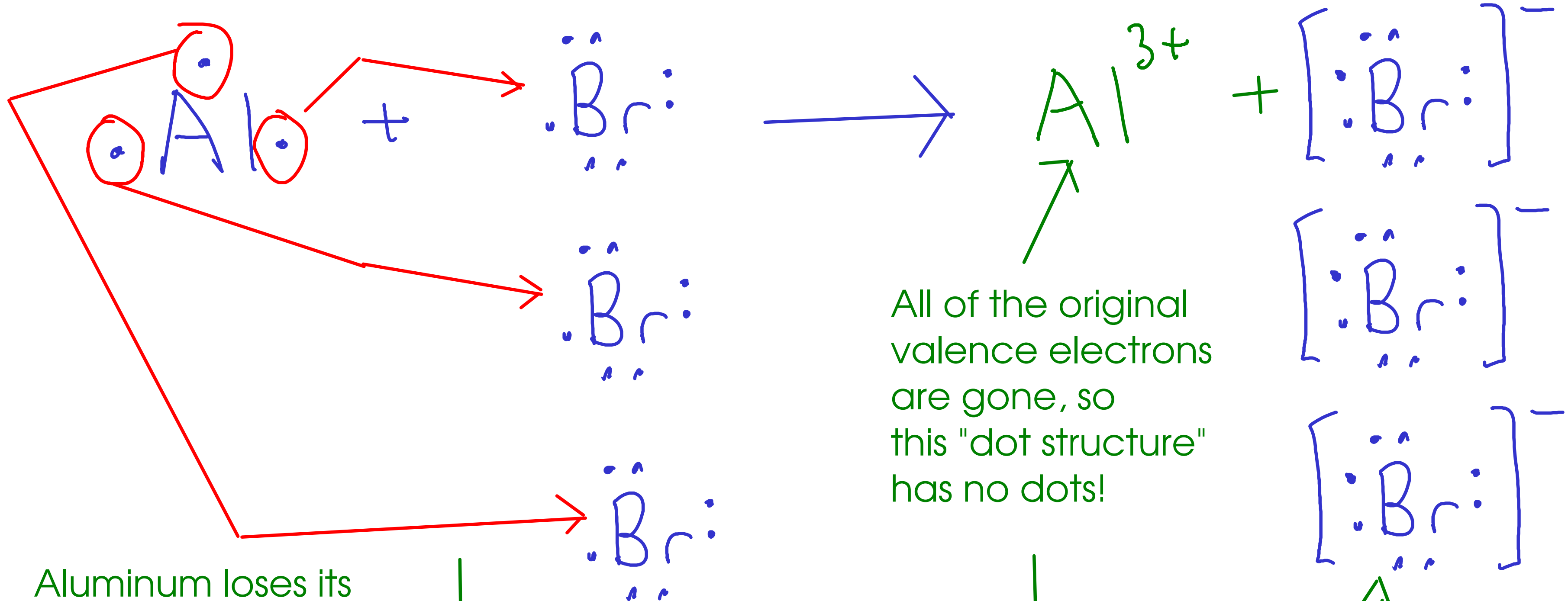
... but how do we use this to describe a reaction that produces ions? Let's look at our previous example!



All of the original valence electrons are gone, so this "dot structure" has no dots!

Aluminum loses its outer three electrons (in the 3s and 3p subshells) (leaving it with full 2s and 2p subshells.

Aluminum is oxidized!

Each bromine atom requires one more electron to get a total of eight outer electrons (full "s" and "p" subshells)

Bromine is reduced!

Each bromide ion has eight outer electrons!

Redox reactions are much clearer when seen using dot notation!

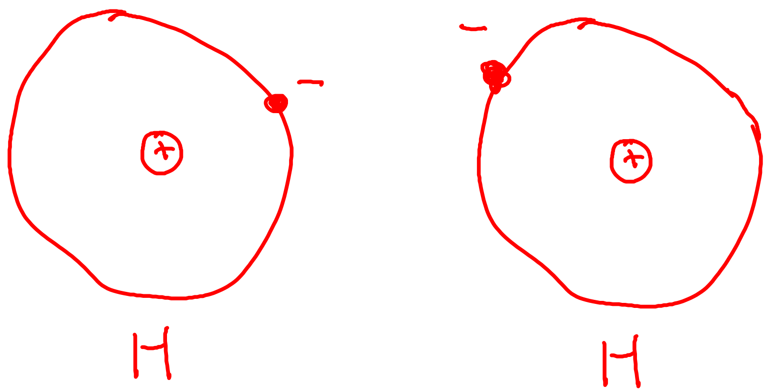
... this is a bit easier to follow than looking at all those letters and numbers in the electron configurations for these elements!

MOLECULAR COMPOUNDS

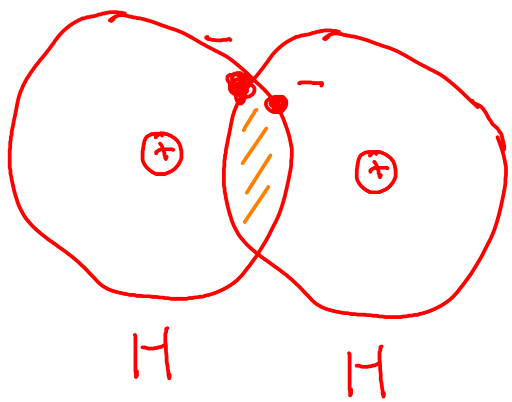
- Form when atoms SHARE electrons instead of transferring them. This results in the formation of MOLECULES ... groups of atoms held together by electron-sharing.

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?

$$H\cdot + \cdot H \longrightarrow H{:}H \,^{*}$$

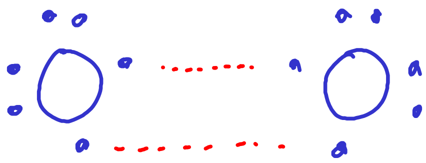
a single shared pair of electrons.
This is called a SINGLE BOND

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

$H{:}H$ becomes $H-H$

* 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.

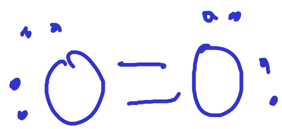
Let's look at OXYGEN ...



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



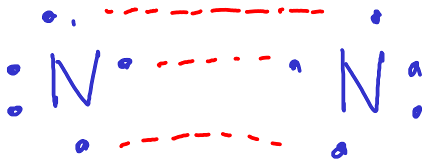
Each oxygen atom has a share in eight electrons!

A few notes on the double bond:

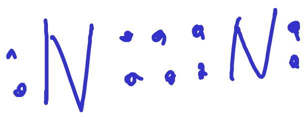
1. - For atoms to share more than one pair of electrons, they have to move closer to one another than they would if they were only sharing one pair of electrons. This BOND DISTANCE is measurable!

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 ...

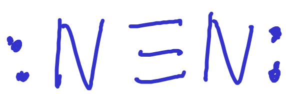


We know that nitrogen exists in air as the diatomic molecule N_2



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.

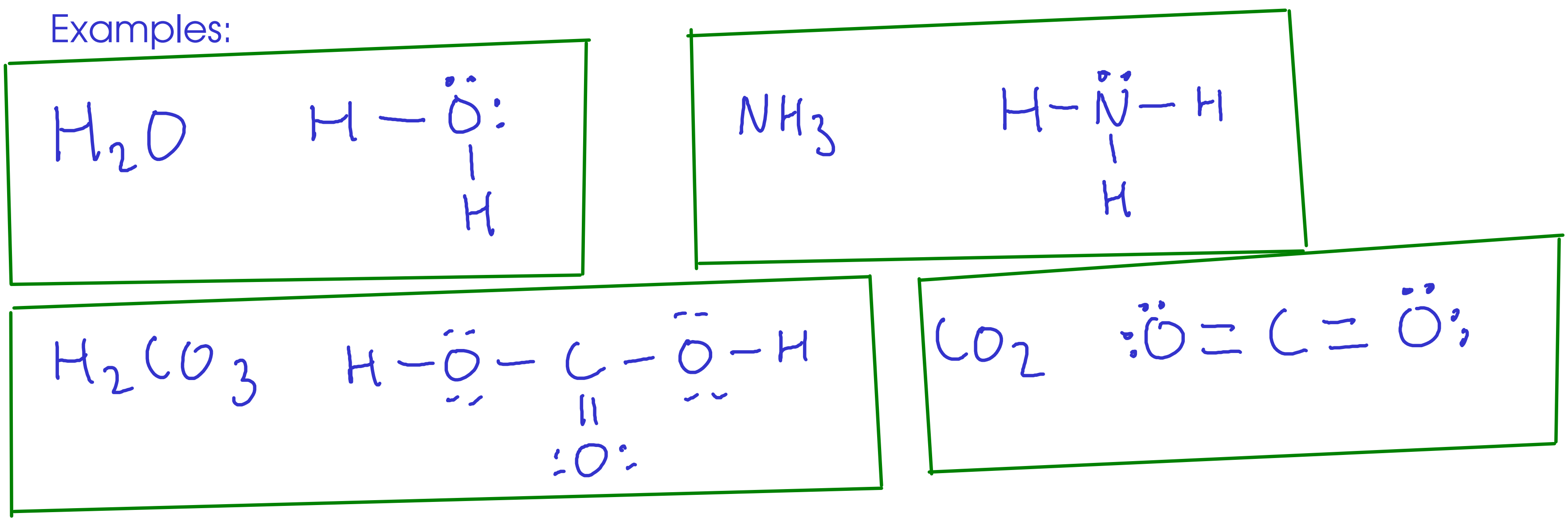
2. Atoms will usually share enough electrons so that each atom ends up with a share in EIGHT electrons - the "octet rule"

    - 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:



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

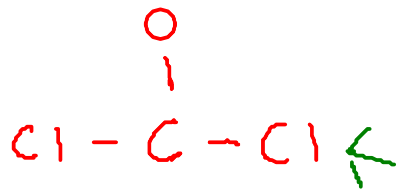
3. Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

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

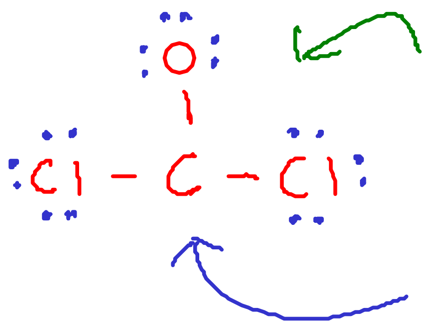
$COCl_2$

C: 4
O: 6
Cl: 2×7 = 14

24 electrons



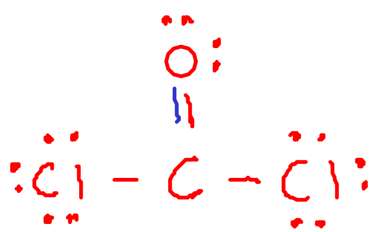
Choose CARBON as the central atom



Distribute remaining electrons. We stop here because we've used all 24 electron

... but CARBON only has a share in SIX electrons, where it should have a share in EIGHT.

We'll pick OXYGEN for the double bond. since it needed an additional TWO electrons at start - and you usually gain one electron for each bond you form.



This structure looks better. Each atom has a share in eight elecfrons.

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

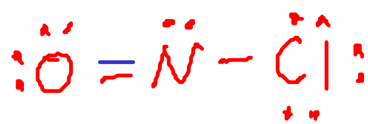
$14e^-$

O – N – Cl

We pick NITROGEN as out central atom since it needs to gain three more electrons. (More than O or Cl)

We ran out of space on the outside before running out of electrons. So, the remaining two electrons go on the NITROGEN.

NITROGEN has a share in only six electrons, so we need a double bond. Pick oxygen again - same reason as for the previous molecule.



Using a pair of electrons from oxygen fixes this structure.

(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

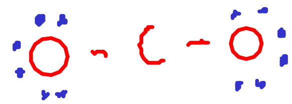
(3) Distribute remaining valence electrons around structure, outer atoms first. Follow octet rule until you run out of electrons.

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

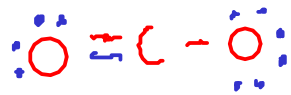
CO_2

C: 4
O: 2×6 = 12

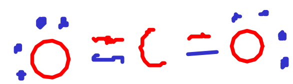
16 electrons



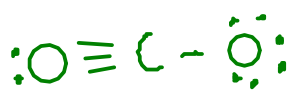
... but each carbon has a share in only FOUR electrons.



... now rhe carbon has a share in SIX electrons



Adding a second double bons with the other oxygen atom fixes this structure and gives each atom a share in eight electrons.



The two oxygen atoms are in identical environments and SHOULD bond in the same way, NOT in the arrangement pictured on the left.

EXPERIMENTALLY, we find that each oxygen atoms in carbon dioxide is the SAME distance from the central carbon atom. This does NOT agree with the triple-bond structure above.

(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.

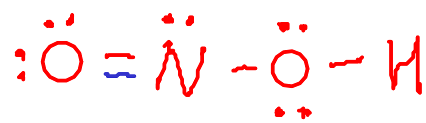
HNO_2 "nitrous acid"

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

H : 1
N : 5
O : 2×6 = 12
18 electrons.

OXYACID - attach H to O

... but NITROGEN has a share in only SIX electrons



Here, the two oxygen atoms are in DIFFERENT chemical environments (one's attached to a hydrogen atom, too) ... so we are not surprised that the bonding is different.