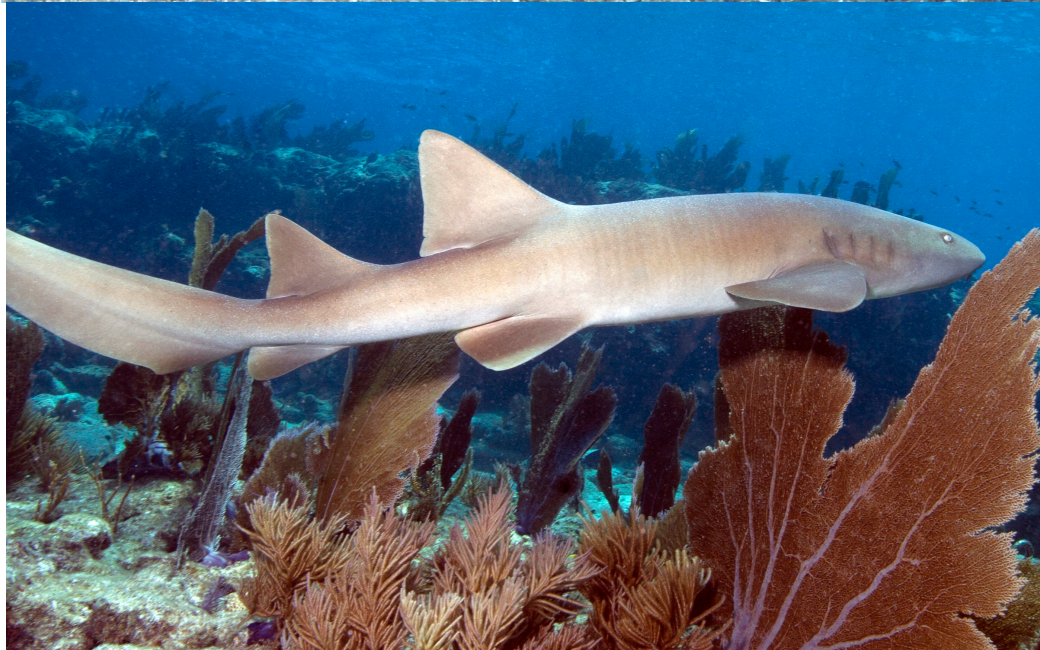
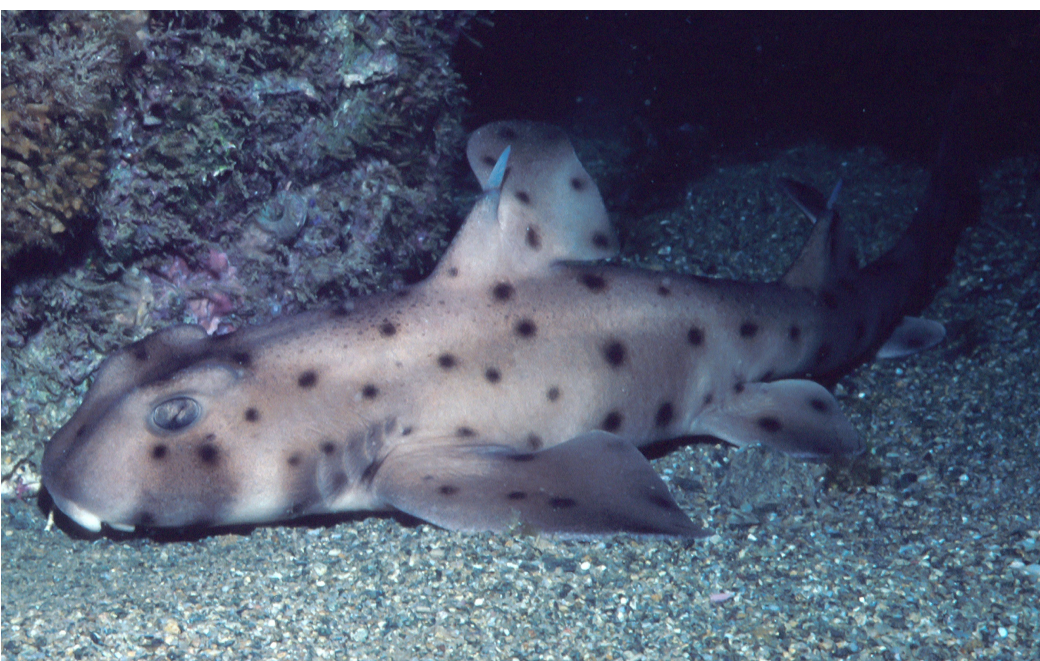
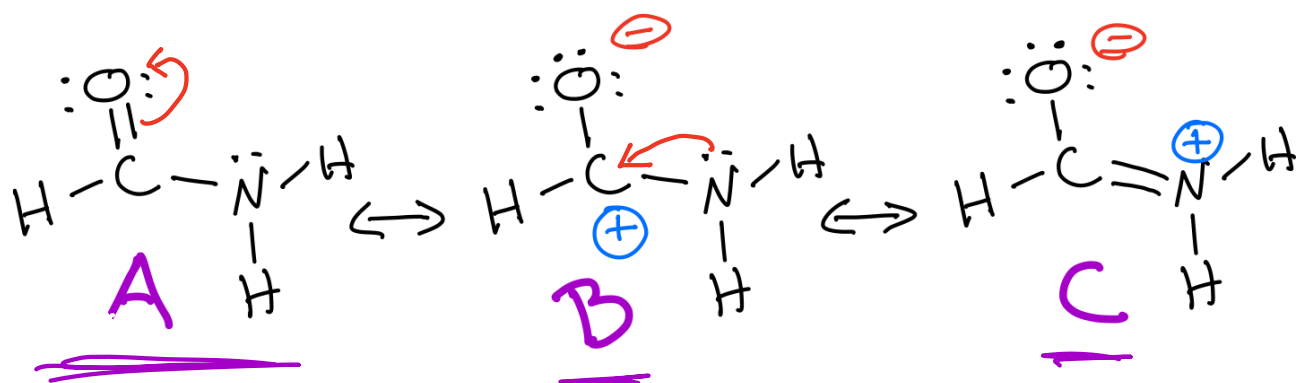






The curious case of amide
contributing structures: All
three are important



Why are B and C
worth considering?



Time
Capsule

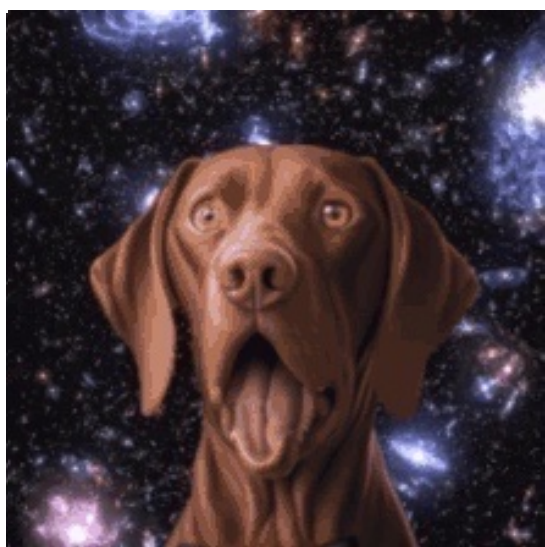
1) Golden Rules of Chemistry
5 and # 7

Quantum Mechanics
Baby!!

Electrons are so incredibly small that they have some properties of particles and some properties of waves

**** For organic chemistry we focus only on the wave properties of electrons!!!

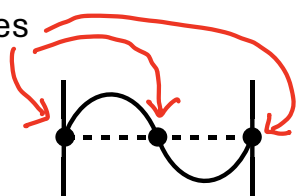
Electrons are three-dimensional waves!!



Properties of Waves → "Energy at a location"

1) Quantized energy → Think of guitar strings

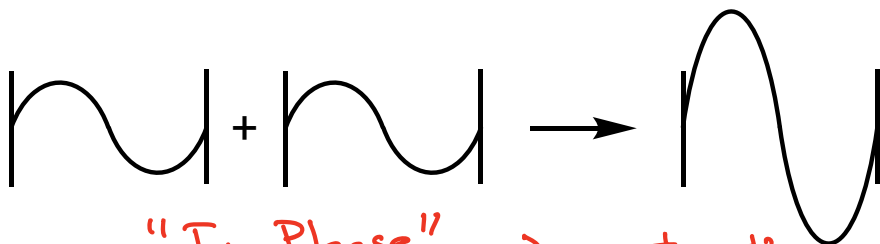
2) Nodes



No energy at certain points in space

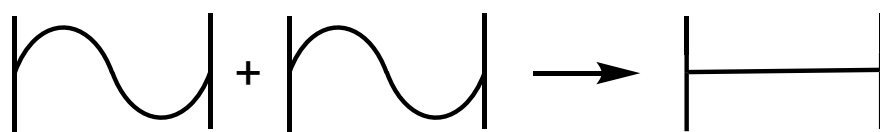
3) Waves add constructively and destructively

Peaks and troughs add



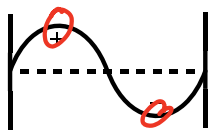
"In Phase" → constructive wave addition

Peaks and troughs cancel



"Out of Phase" → destructive wave addition

4) There is just as much energy at the top (+) amplitude of a wave as there is as the bottom (-) amplitude of a wave.



5) If you add X wave equations you get X new equations

The basis of molecular orbital theory

6) Around atoms, the location of electron density is described by the Schrödinger equation

A wave equation that describes energy and location

Solutions to the Schrodinger equation – atomic orbitals

$$\psi_{nlm}(r, \theta, \phi) = \sqrt{\left(\frac{2}{na_0}\right)^3 \frac{(n-\ell-1)!}{2n[(n+\ell)!]}} e^{-r/na_0} \left(\frac{2r}{na_0}\right)^\ell L_{n-\ell-1}^{2\ell+1}\left(\frac{2r}{na_0}\right) \cdot Y_\ell^m(\theta, \phi)$$

where:

- $a_0 = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2}$ is the **Bohr radius**,
- $L_{n-\ell-1}^{2\ell+1}(\dots)$ are the **generalized Laguerre polynomials** of degree $n - \ell - 1$.
- n, ℓ, m are the **principal, azimuthal, and magnetic quantum numbers** respectively: which take the values:
 $n = 1, 2, 3, \dots$
 $\ell = 0, 1, 2, \dots, n - 1$
 $m = -\ell, \dots, \ell$

e⁻ density $\rightarrow$ 3d wave!

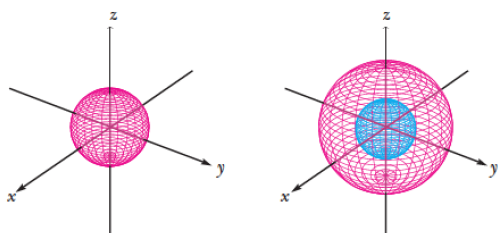
Ψ_{1s}

Ψ_{2s}

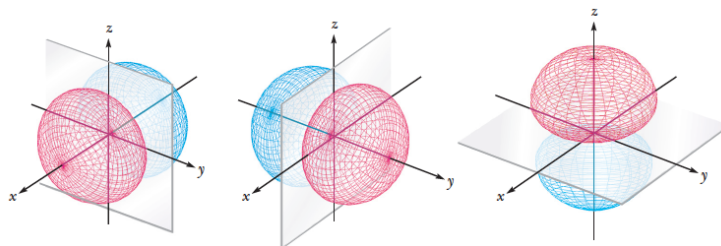
Ψ_{2p_x}

Ψ_{2p_y}

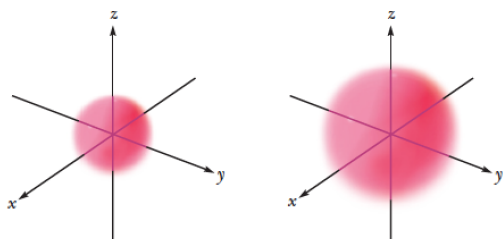
Ψ_{2p_z}



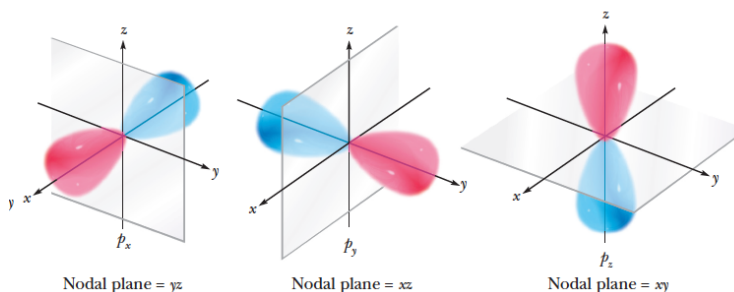
(a) 1s and 2s orbitals computed using the Schrödinger equation



(a) 2p Orbitals computed using the Schrödinger equation



(b) Cartoon representations of 1s and 2s orbitals



Different colors represent the sign of the wave function (+ or -)

We plot the square of the wave function (Ψ^2) and refer to this as an "orbital"

Molecular Orbital Theory

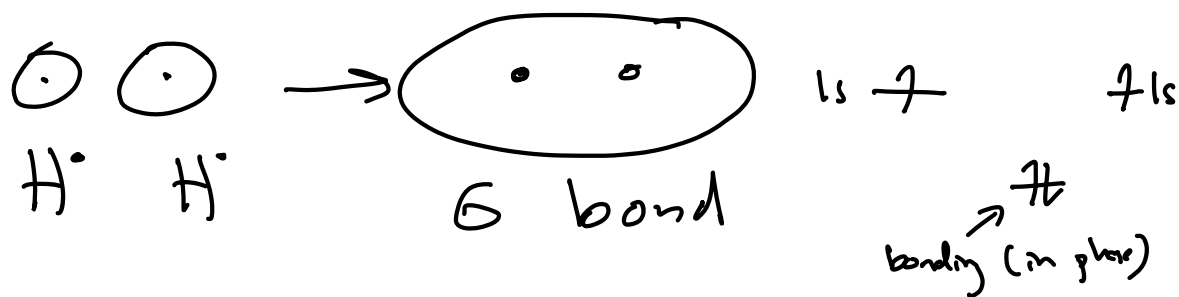
→ To quantify bonding in molecules we simply add all of the atomic orbital wave functions in the molecule

- 1) This creates as many new molecular orbitals as there are component orbitals being added.
- 2) Each molecular orbital extends over the ENTIRE molecule
- 3) Each new molecular orbital contains up to the electron density equal to 2 electrons
⇒ NEVER MORE

All of this can explain π bonds, but it only works for computers to explain σ bonds → humans needed another approach —

Before we get to Valence Bond Theory, let's review σ bonds and π bonds

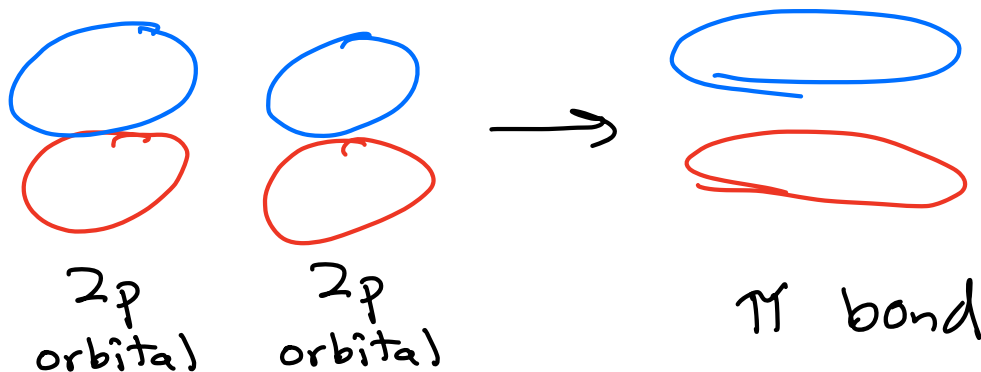
σ bonds $\rightarrow$ cylindrical symmetry
 $\rightarrow$ rotate freely



π bond $\rightarrow$ "hot dog bun shape"

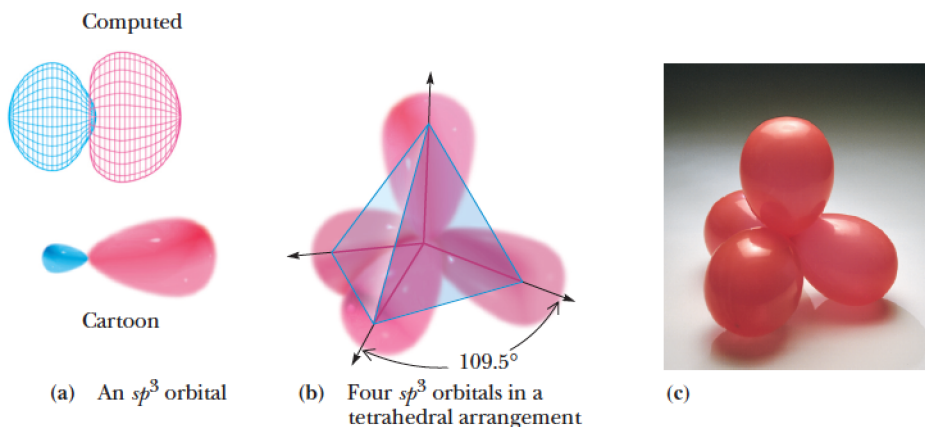
$\rightarrow$ CANNOT rotate freely

$\rightarrow$ Formed from the overlap of 2p orbitals

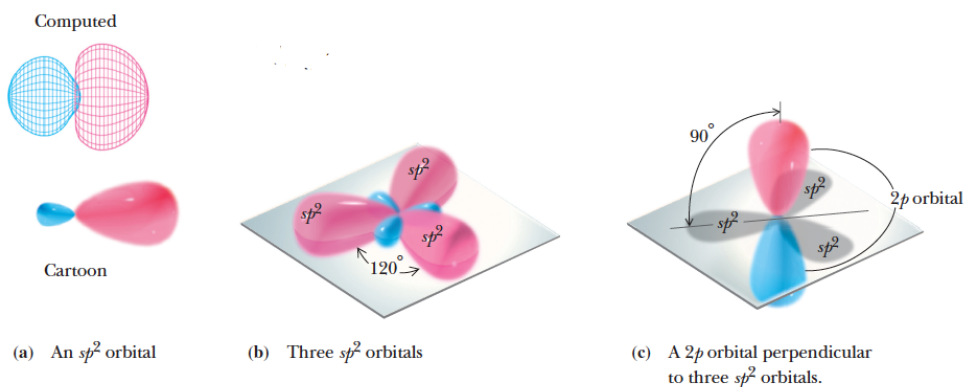


Hybridization – Valence Bond Approach to bonding

$$sp^3 (\Psi_{2s} + \Psi_{2p_x} + \Psi_{2p_y} + \Psi_{2p_z})$$



$$sp^2 (\Psi_{2s} + \Psi_{2p_x} + \Psi_{2p_y}) + \Psi_{2p_z}$$



$$sp (\Psi_{2s} + \Psi_{2p_x}) + \Psi_{2p_y} + \Psi_{2p_z}$$

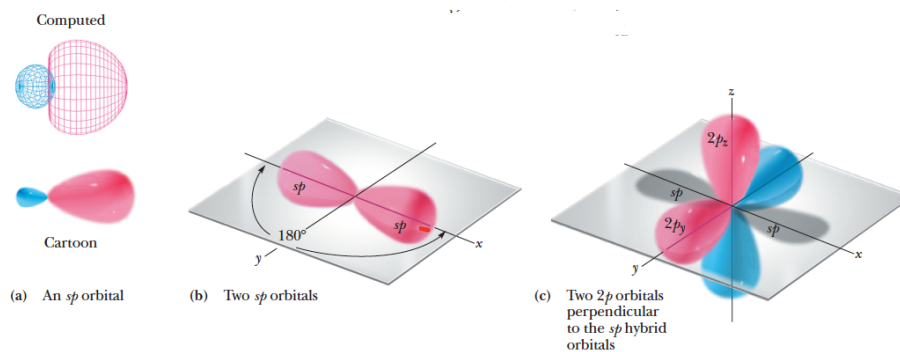


Figure 1.18

Molecular orbital mixing diagram for the creation of any C—C σ bond. (a) In-phase addition of two C hybrid orbitals (albeit sp^3 , sp^2 , or sp orbital) forms a σ orbital that is lower in energy than the two starting orbitals. When the resulting orbital is populated with two electrons, a σ bond results. (b) Addition of the orbitals in an out-of-phase manner (meaning reversing the phasing of one of the starting orbitals) leads to an antibonding σ^* orbital.

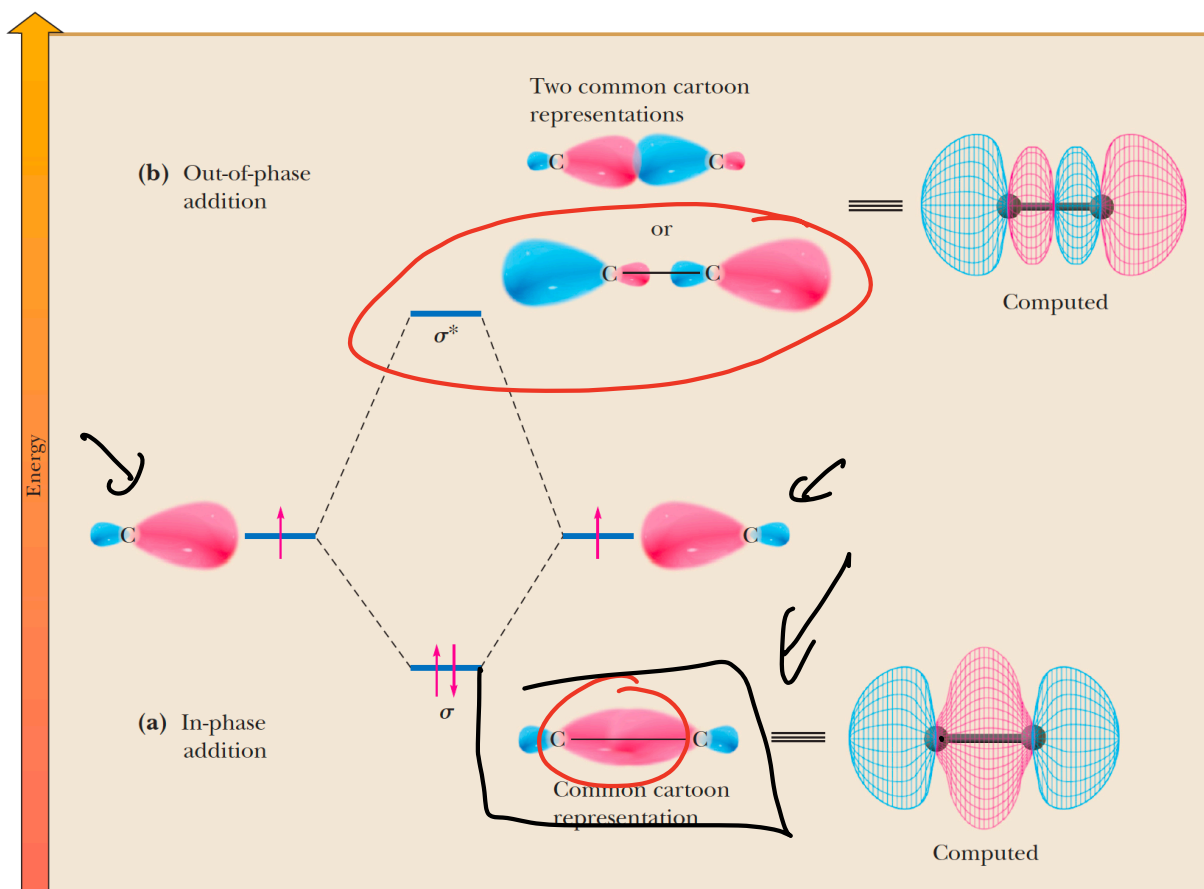
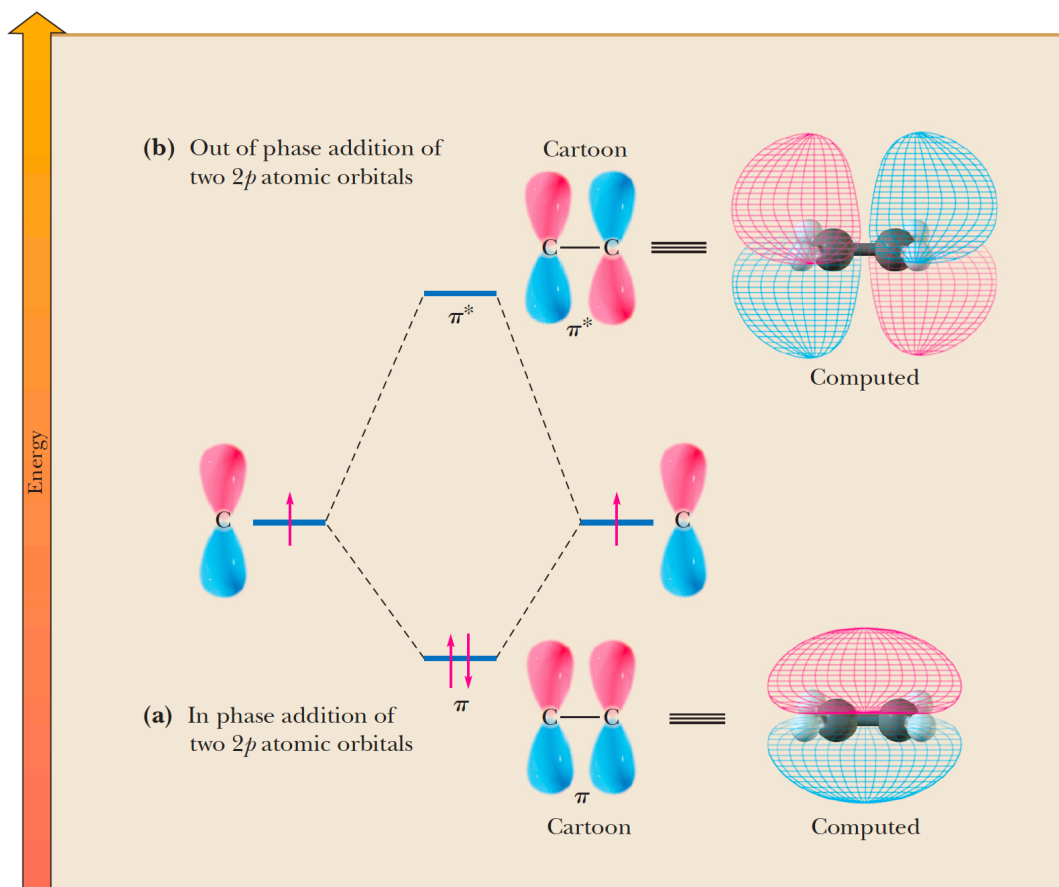
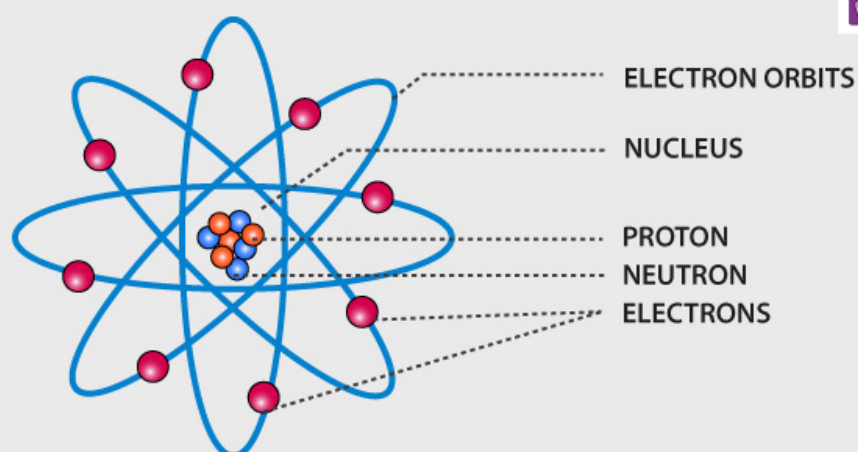


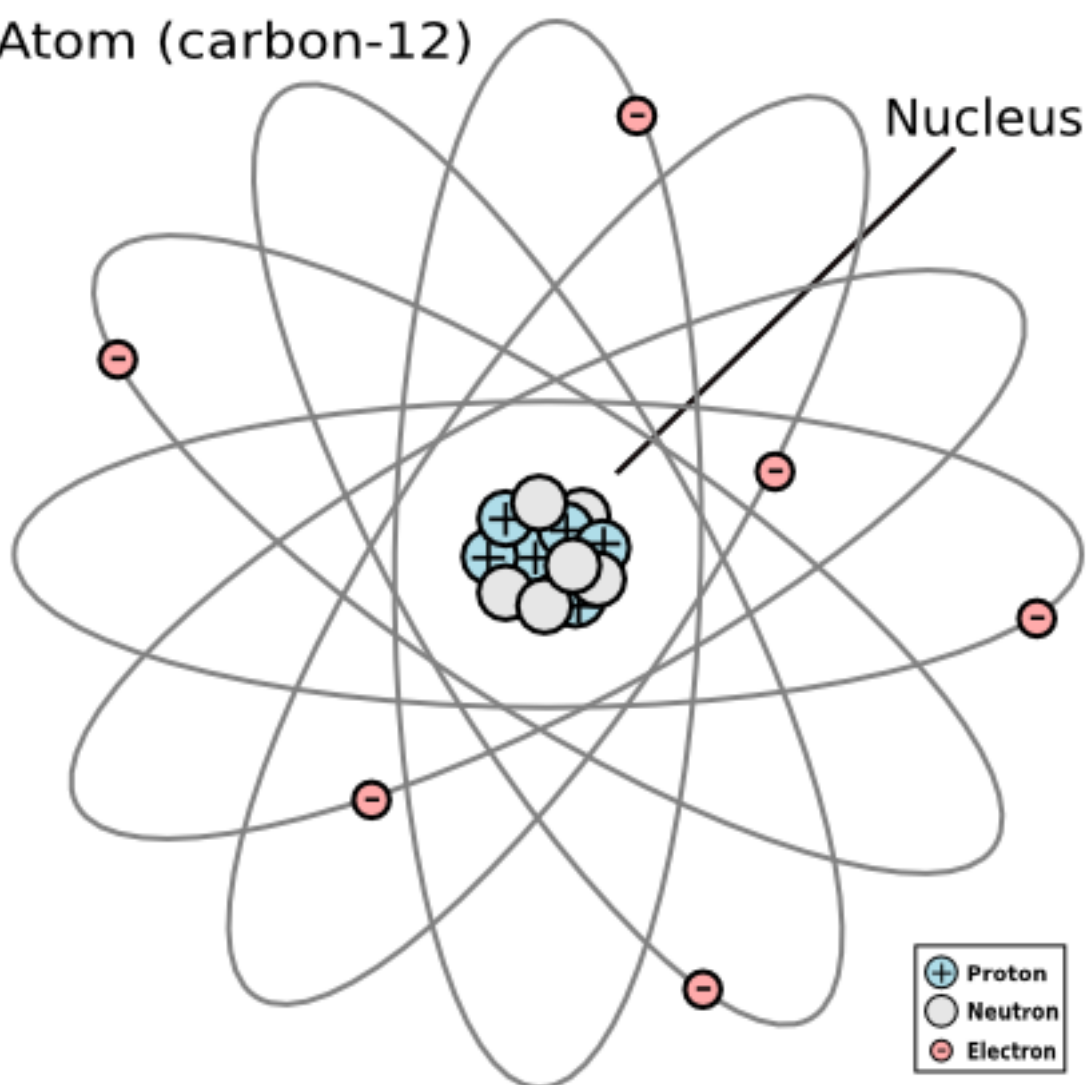
Figure 1.21

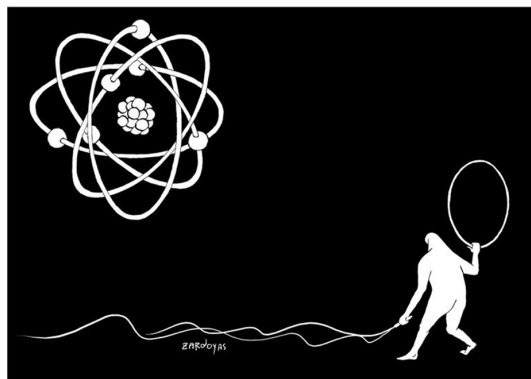
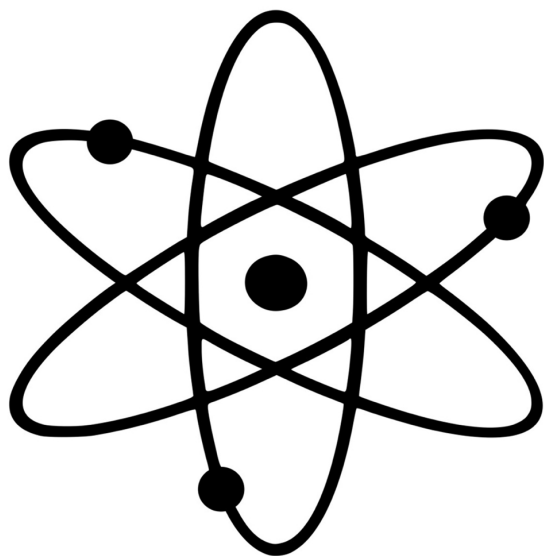
Molecular orbital mixing diagram for the creation of any C—C π bond. (a) Addition of two p atomic orbitals in-phase leads to a π orbital that is lower in energy than the two separate starting orbitals. When populated with two electrons the π orbital gives a π bond. (b) Addition of the p orbitals in an out-of-phase manner (meaning a reversal of phasing in one of the starting orbitals) leads to a π^* orbital. Population of this orbital with one or two electrons leads to weakening or cleavage of the π bond respectively.

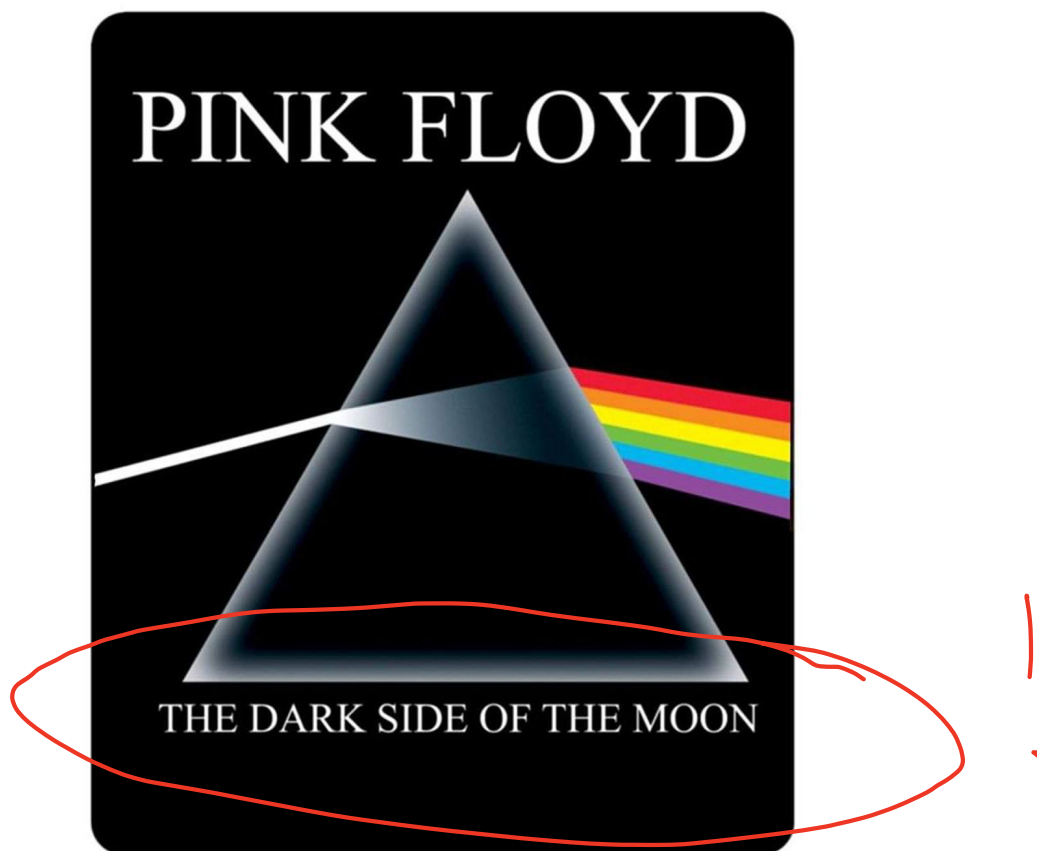


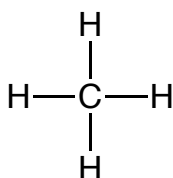


Atom (carbon-12)









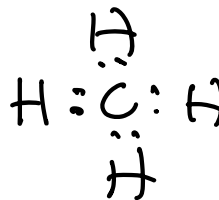
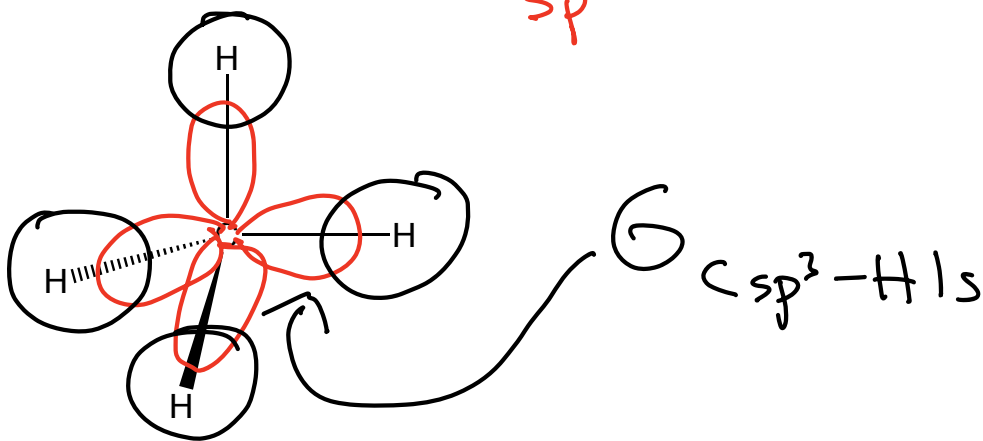
Methane

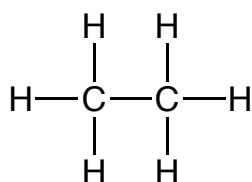
Molecular Orbital Theory approach to bonding: Just add the individual orbital wave functions:

$$\underbrace{\Psi_{\text{H}1s}} + \underbrace{\Psi_{\text{H}1s}} + \underbrace{\Psi_{\text{H}1s}} + \underbrace{\Psi_{\text{H}1s}} + \underbrace{\Psi_{\text{C}1s}} + \underbrace{\Psi_{\text{C}2s}} + \underbrace{\Psi_{\text{C}2p_x}} + \underbrace{\Psi_{\text{C}2p_y}} + \underbrace{\Psi_{\text{C}2p_z}}$$

Valence Bond Theory approach to bonding: Hybridize the atomic orbitals on atoms first, then look for overlap with remaining orbital wave functions:

$$\Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \underbrace{\Psi_{\text{C}1s} + (\Psi_{\text{C}2s} + \Psi_{\text{C}2p_x} + \Psi_{\text{C}2p_y} + \Psi_{\text{C}2p_z})}_{sp^3}$$





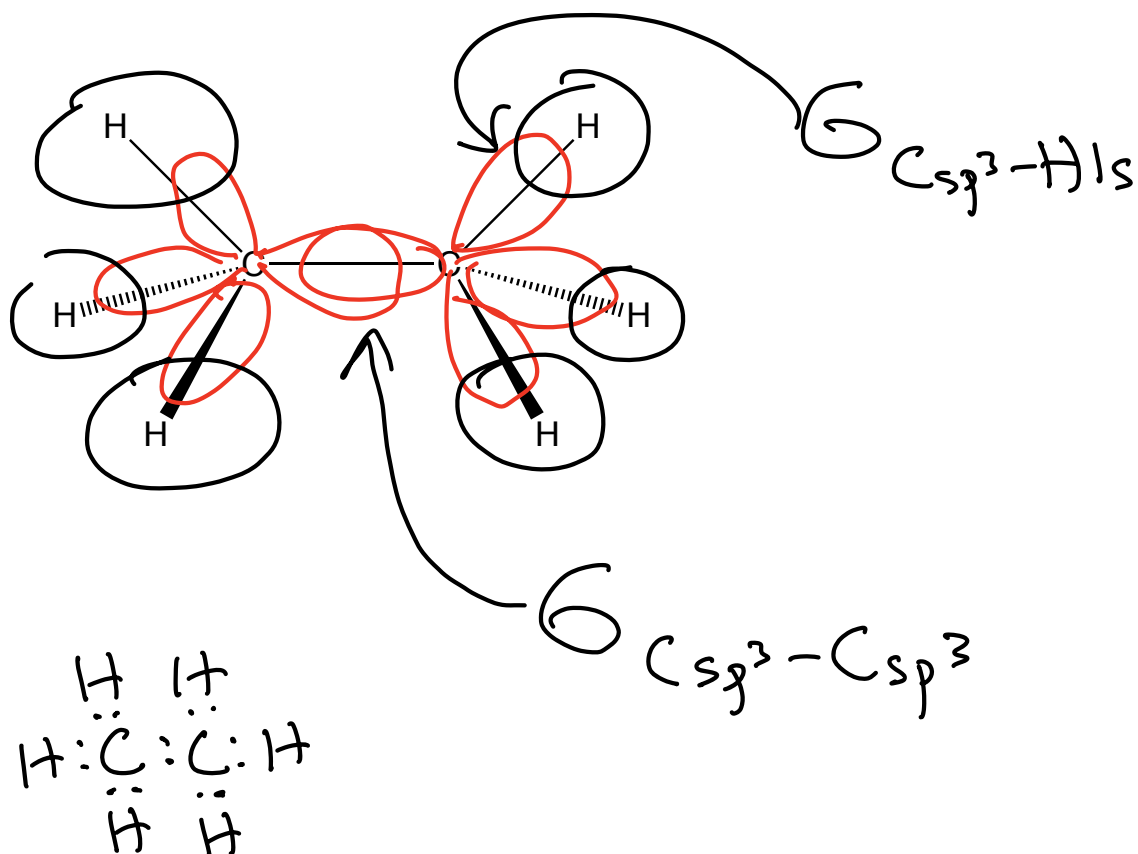
Ethane

Molecular Orbital Theory approach to bonding: Just add the individual orbital wave functions:

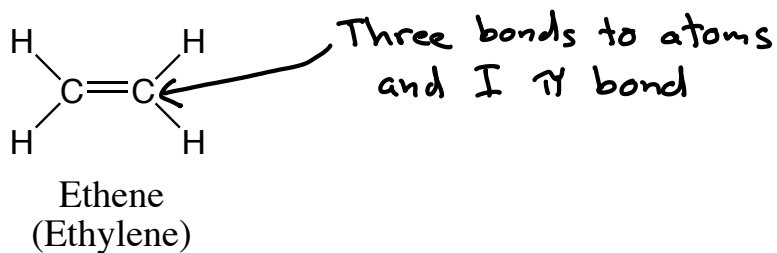
$$\begin{aligned}
 &\Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{C}1s} + \Psi_{\text{C}2s} + \Psi_{\text{C}2p_x} \\
 &+ \Psi_{\text{C}2p_y} + \Psi_{\text{C}2p_z} + \Psi_{\text{C}1s} + \Psi_{\text{C}2s} + \Psi_{\text{C}2p_x} + \Psi_{\text{C}2p_y} + \Psi_{\text{C}2p_z}
 \end{aligned}$$

Valence Bond Theory approach to bonding: Hybridize the atomic orbitals on atoms first, then look for overlap with remaining orbital wave functions:

$$\begin{aligned}
 &\Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{C}1s} + (\Psi_{\text{C}2s} + \Psi_{\text{C}2p_x} \\
 &+ \Psi_{\text{C}2p_y} + \Psi_{\text{C}2p_z}) + \Psi_{\text{C}1s} + (\Psi_{\text{C}2s} + \Psi_{\text{C}2p_x} + \Psi_{\text{C}2p_y} + \Psi_{\text{C}2p_z}) \quad \begin{matrix} s^3 \\ s^3 \end{matrix}
 \end{aligned}$$



Review from
up above!

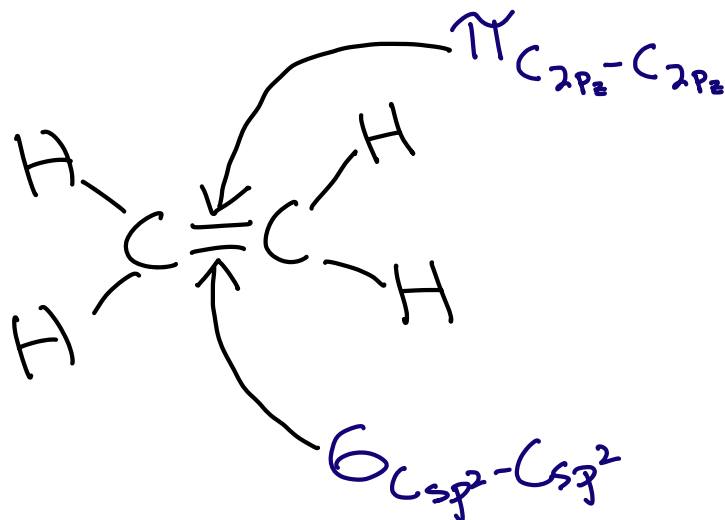
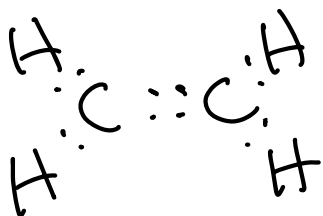
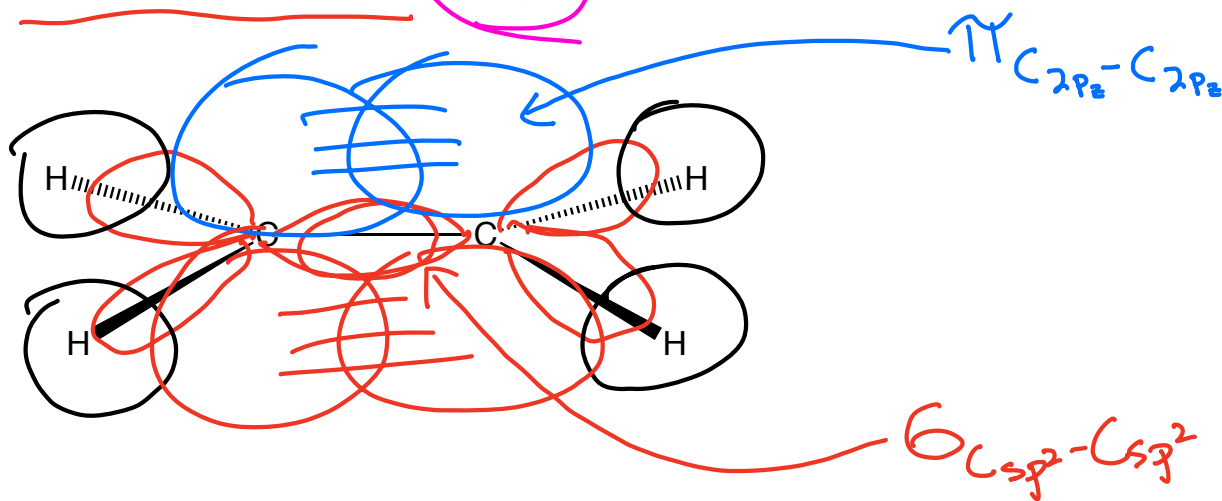


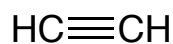
Molecular Orbital Theory approach to bonding: Just add the individual orbital wave functions:

$$\Psi_{H1s} + \Psi_{H1s} + \Psi_{H1s} + \Psi_{H1s} + \Psi_{C1s} + \Psi_{C2s} + \Psi_{C2px} + \Psi_{C2py} + \Psi_{C2pz} \\ + \Psi_{C1s} + \Psi_{C2s} + \Psi_{C2px} + \Psi_{C2py} + \Psi_{C2pz}$$

Valence Bond Theory approach to bonding: Hybridize the atomic orbitals on atoms first, then look for overlap with remaining orbital wave functions:

$$\Psi_{H1s} + \Psi_{H1s} + \Psi_{H1s} + \Psi_{H1s} + \Psi_{C1s} + (\Psi_{C2s} + \Psi_{C2px} + \Psi_{C2py}) + \Psi_{C2pz} \\ + \Psi_{C1s} + (\Psi_{C2s} + \Psi_{C2px} + \Psi_{C2py}) + \Psi_{C2pz}$$





Ethyne
(Acetylene)

Molecular Orbital Theory approach to bonding: Just add the individual orbital wave functions:

$$\Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{C}1s} + \Psi_{\text{C}2s} + \Psi_{\text{C}2px} + \Psi_{\text{C}2py} + \Psi_{\text{C}2pz} + \Psi_{\text{C}1s} \\ + \Psi_{\text{C}2s} + \Psi_{\text{C}2px} + \Psi_{\text{C}2py} + \Psi_{\text{C}2pz}$$

Valence Bond Theory approach to bonding: Hybridize the atomic orbitals on atoms first, then look for overlap with remaining orbital wave functions:

$$\Psi_{\text{H}1s} + \Psi_{\text{H}1s} + \Psi_{\text{C}1s} + (\Psi_{\text{C}2s} + \Psi_{\text{C}2px}) + \Psi_{\text{C}2py} + \Psi_{\text{C}2pz} + \Psi_{\text{C}1s} \\ + (\Psi_{\text{C}2s} + \Psi_{\text{C}2px}) + \Psi_{\text{C}2py} + \Psi_{\text{C}2pz}$$

Handwritten annotations: A bracket labeled 's' groups the first two H 1s orbitals. A bracket labeled 'sp' groups the C 2s and 2px orbitals. The C 2py and C 2pz orbitals are circled in blue.

