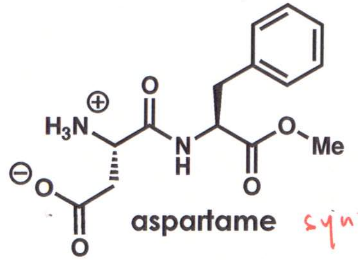
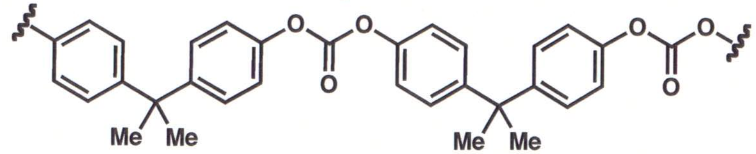
You Are Already Familiar With Organic Chemistry

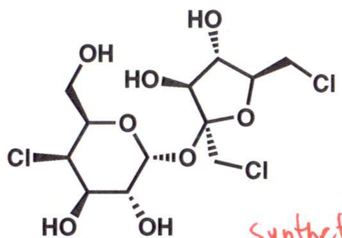


aspartame synthetic

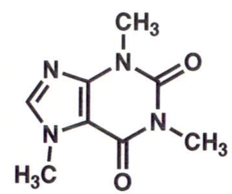
synthetic



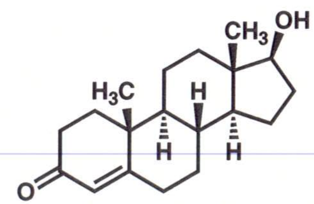
polycarbonate derived from bis-phenol A



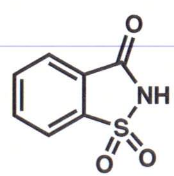
sucrulose synthetic



caffeine

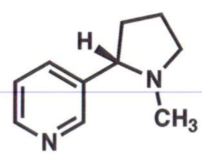


testosterone



saccharin

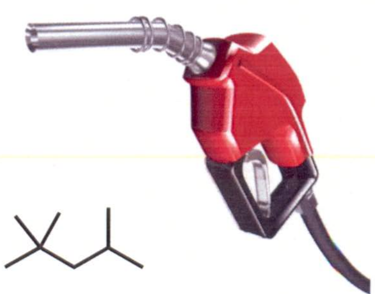
synthetic

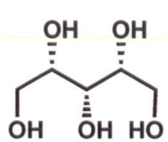


nicotine

gasoline: mixture of hydrocarbons between 5 and 12 carbons

n = 0–5





xylitol

(33% fewer calories)

Organic Chemistry: It's All About Carbon (and a few other elements)

What is a chemical reaction?

$$\underbrace{CH_4\,(g) + 2\,O_2\,(g)}_{\text{reactants}} \longrightarrow \underbrace{CO_2\,(g) + 2\,H_2O\,(l)}_{\text{products}}$$

- a change in the chemical composition...
- breaking 4 C-H bonds and 2 O=O bonds; forming two C=O bonds and 4 O-H bonds
- follow the rules of stoichiometry

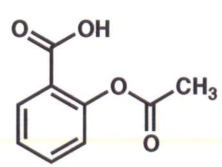
Reactions can be endothermic (requires heat) or exothermic (releases heat)

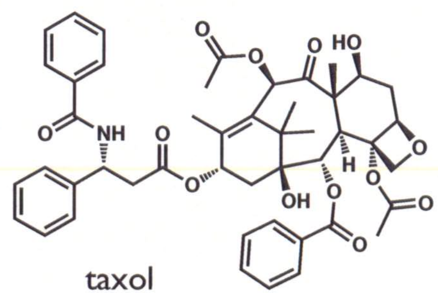
Organic chemistry: the chemistry of carbon
- covalent bonding predominates

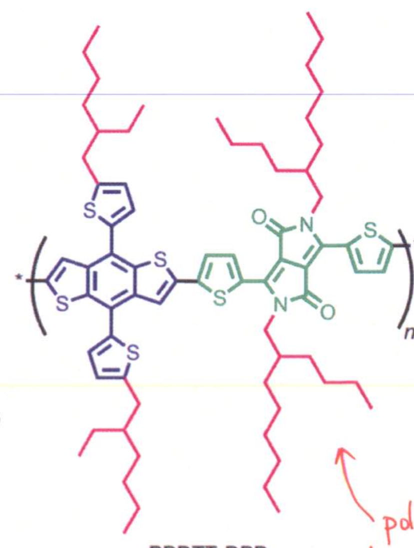
remember, C has electronegativity value of 2.6 right in the middle (values range from 0.9 to 4; difference between 0.4 and 2.7 are considered covalent)

Synthetic organic chemistry: the science of making carbon-based compounds. Applications in

- materials science
- drug discovery and development


aspirin


taxol
"paclitaxel"


PBDTT-DPP

polymer used in organic photovoltaic cells

Organic Reactions: Understanding Reactivity

From a first approximation, many organic reactions can be explained in terms of dipoles and charge attraction:

- when two molecules with complementary dipoles collide with the required activation energy to overcome general electronic repulsion, a chemical change or reaction follows.

an extreme example (from the world of inorganic chemistry):

strong covalent bond   strong ionic bond

$$Na^{\oplus}\ {}^{\ominus}OH \; + \; H^{\oplus}\ Cl^{\ominus} \longrightarrow H-OH \; + \; NaCl$$

exchange the charged species... ${}^{\ominus}OH$ reacts with ${}^{\oplus}H$

$Cl^{\ominus}$ reacts with $Na^{\oplus}$

a more subtle example:

weaker covalent bond   strong covalent bond   strong ionic bond

$$\underset{\delta^{\ominus}}{Br} - \underset{\delta^{\oplus}}{CH_3} \; + \; Na^{\oplus}\ {}^{\ominus}CN \longrightarrow H_3C-CN \; + \; NaBr$$

the negatively charged cyanide reacts at the partially positively charged carbon

we can use "arrows" to indicate the flow of electrons in a reaction: mechanism

$$Br-CH_3 \; + \; {}^{\ominus}CN \longrightarrow Br^{\ominus} \; + \; H_3C-CN$$

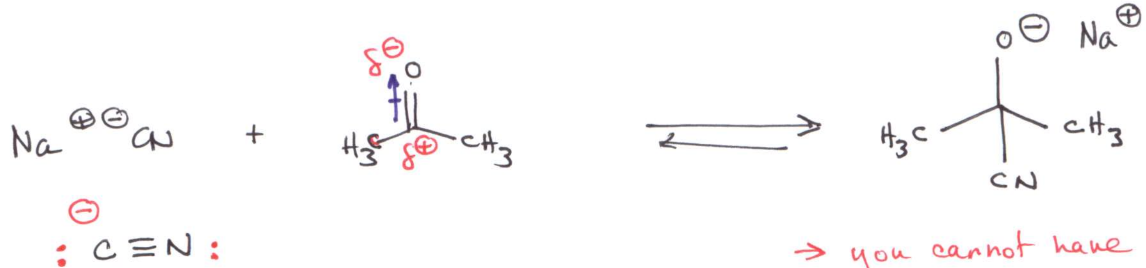
we'll come back to this

analysis of the reagents in terms of bond dipoles and electronegativity allows you to predict reactivity (to a certain extent)

Organic Reactions: Understanding Reactivity

Additional examples:

a charged species can react with neutral compound



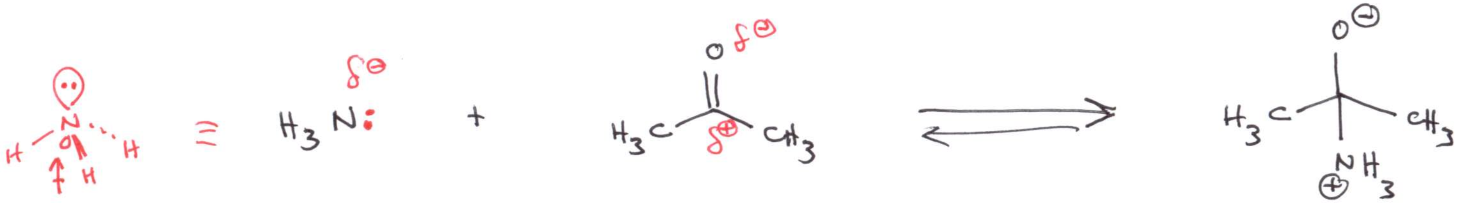
formal (-) charge on carbon

the negatively charged cyanide reacts at the partially positive charged carbon

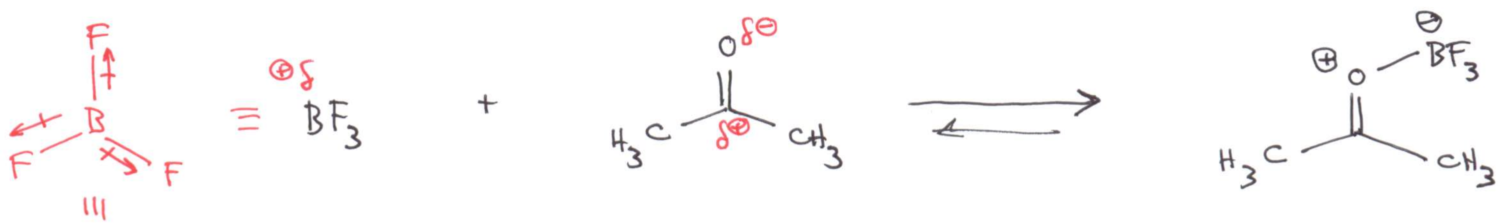
→ you cannot have 5 bonds to carbon, so the C=O double bond is broken

two neutral compounds can react

(a filled orbital is reacting with a vacant orbital)



the non-bonded electrons in the N lone pair react with the partially positive charged carbon



partially negatively charged oxygen reacts with partially positively charged boron

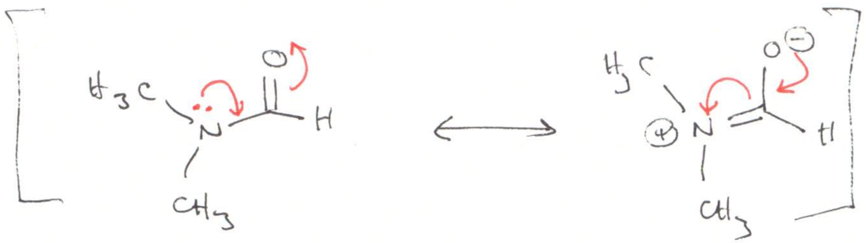
empty p-orbital

In all of these cases, analysis of the bond and molecular dipoles can help you 'intuit' the chemical reactivity

Curved Arrows: A Formalism to Indicate Electron Flow

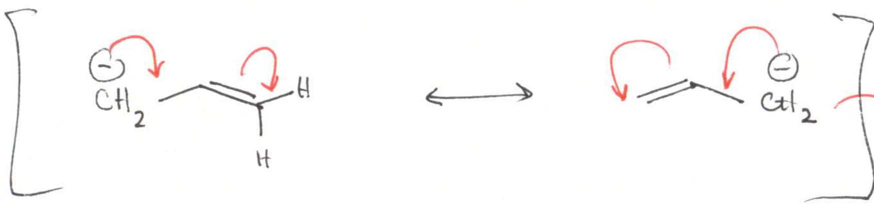
Curved arrows can also be used to demonstrate resonance structures

remember dimethyl formamide?



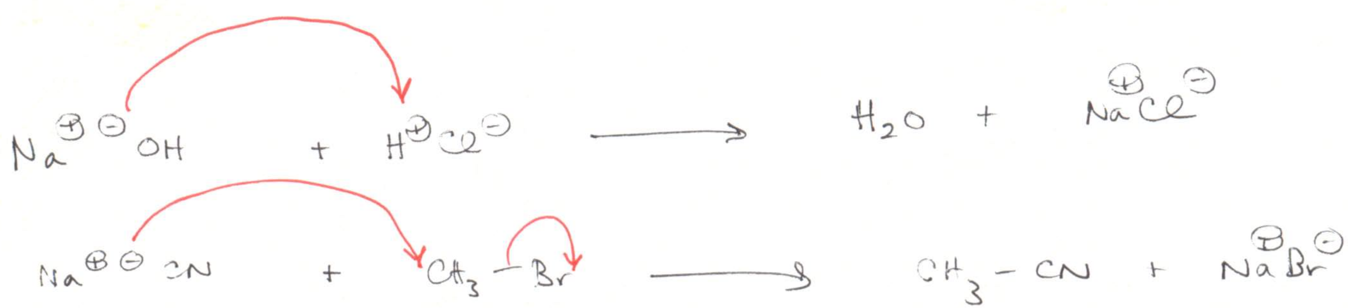
- overall charge (net charge is conserved)
- nitrogen lone pair is delocalized; N is sp^2 hybridized, N–C bond has high barrier to rotation

allyl anion?



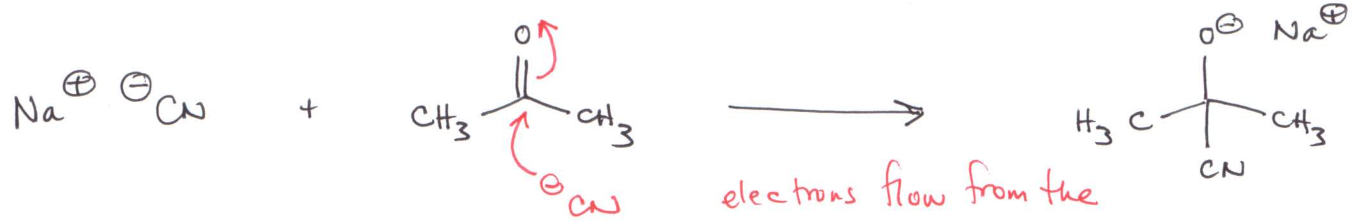
carbon is sp^2 hybridized; anion resides in p-orbital to permit delocalization

Curved arrows also indicate reaction mechanisms:

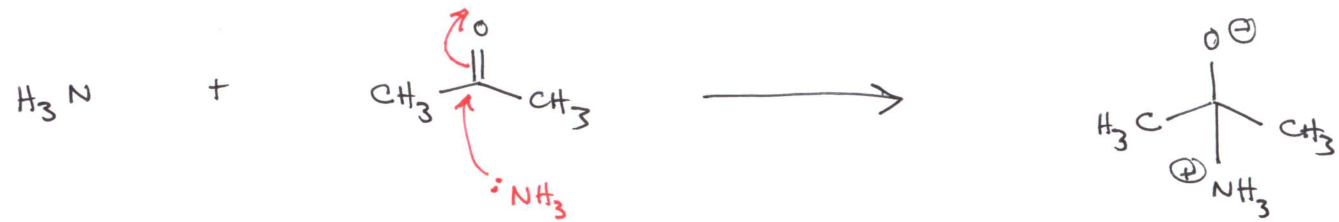


Curved Arrows: A Formalism to Indicate Electron Flow

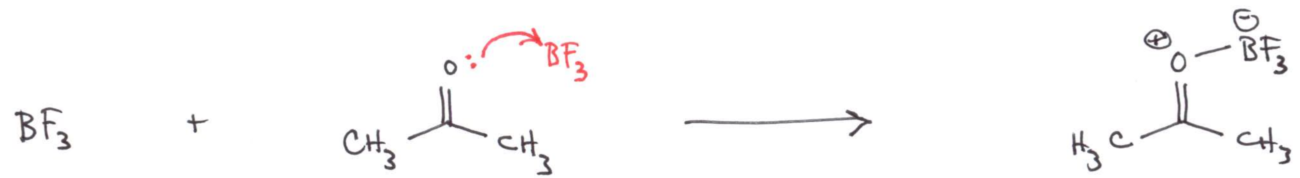
Organic chemists use curved arrows to represent reaction mechanisms



electrons flow from the cyanide anion to the carbonyl oxygen



organic chemists refer to this arrow pushing as a "reaction mechanism"



electrons flow from the carbonyl lone pair to the vacant Boron p-orbital

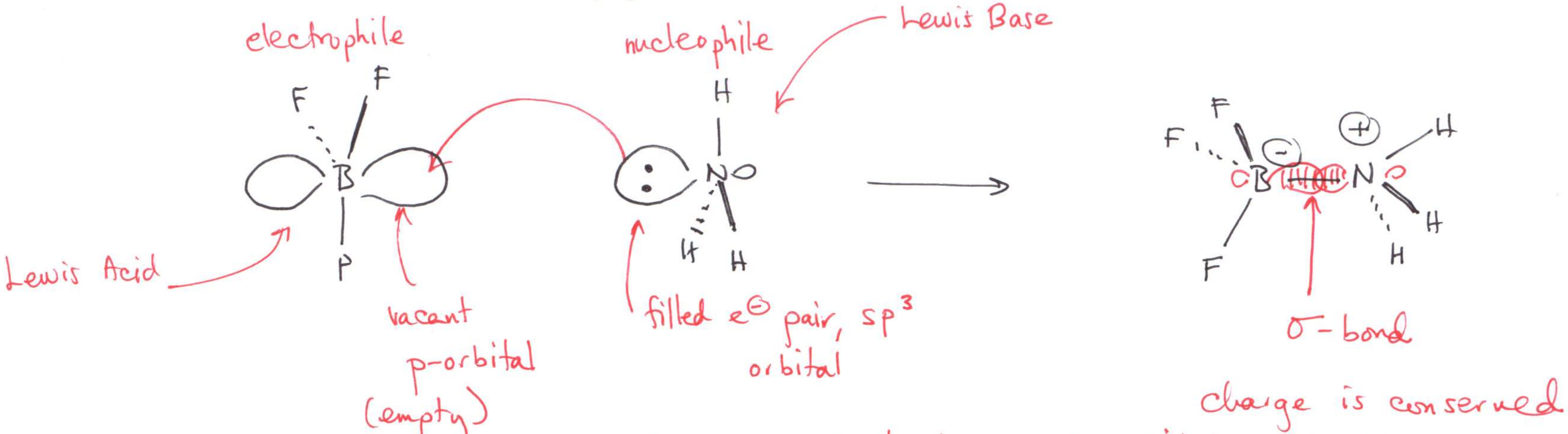
"pushing electrons" using curved arrows: rules to live by

- a curved arrow indicates the movement of a pair of electrons (NOT ATOMS)
- the curved arrow originates at an electron pair (a filled orbital)
- the head of the arrow indicates the final destination of the electron pair
- overall charge MUST be conserved in a reaction
- the octet rule MUST be followed: if you make a new bond, you MUST *break* an old bond (most of the time)

MO theory and Chemical Reactivity

Complimentary dipoles are important, but not *enough* to explain reactivity: we need to consider orbital overlap, too.

- interactions between filled and empty orbitals can result in a chemical reaction



In a generic sense:

there needs to be good orbital overlap!!

push electrons from the nucleophile to the electrophile

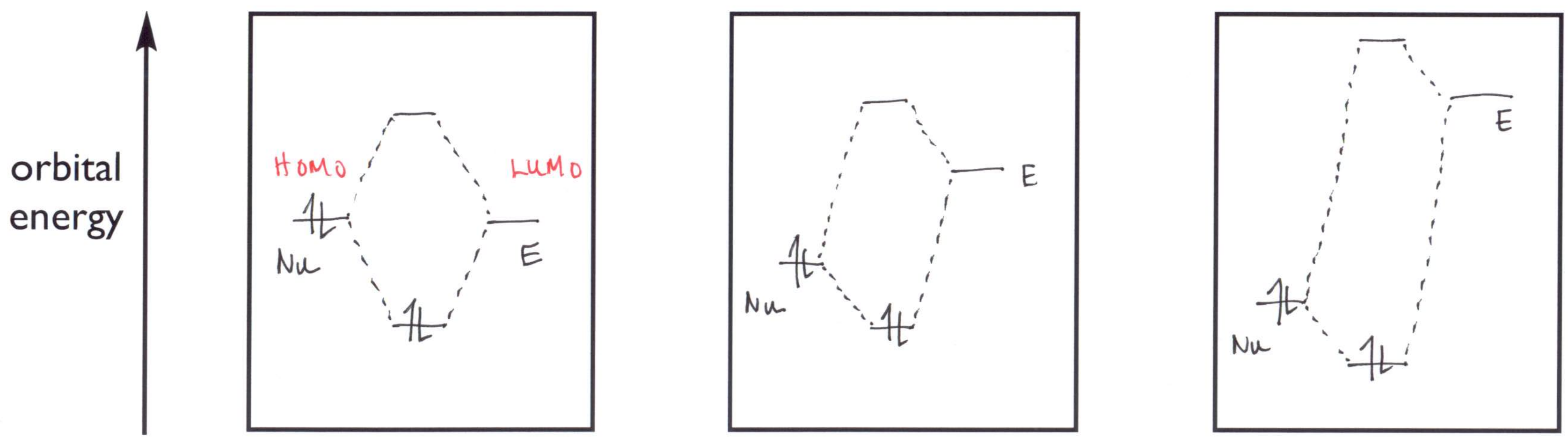
electrophile: ‘electron-lover’, accepts an electron pair during a chemical reaction

nucleophile: ‘nucleus-lover’, donates an electron pair during a chemical reaction, is attracted to electron-deficient reagents

MO theory and Chemical Reactivity

Complimentary dipoles can be important, but are not *enough* to explain reactivity: we need to consider orbital overlap, too.

- interactions between filled (HOMO) and empty (LUMO) orbitals can result in a chemical reaction
- the energies of two reacting orbitals need to be relatively close for reactions to occur



ideal

more likely

won't happen!

there needs to be relatively good matching of HOMO and LUMO energies for reaction to occur... if the energy difference is too big, no reaction will occur

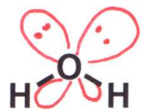
- filled orbitals tend to be lower in energy than empty orbitals (that's why they're filled!)

Nucleophiles

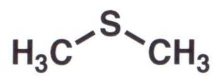
Nucleophiles donate high energy electrons from a filled orbital (HOMO) to an electrophile

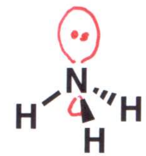
in general, non-bonded $e^{\ominus}$s are higher in energy than bonding electrons; therefore lone pairs are typically the HOMO for a molecule

neutral lone pair nucleophiles:

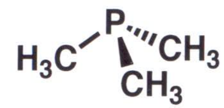


two lone pairs in sp^3 hybridized orbitals





one lone pair in an sp^3 hybridized orbital



non-bonded electrons (lone-pairs) are stabilized by more electronegative atoms/orbitals.

which has the higher HOMO, OH_2 or NH_3?

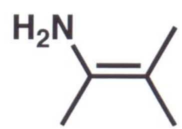
which is more nucleophilic?

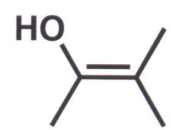
anionic lone pair nucleophiles:

$^{\ominus}$OH $\quad$ $^{\ominus}$$SCH_3$ $\quad$ $^{\ominus}$CN $\quad$ $^{\ominus}$I $\quad$ $^{\ominus}$Br $\quad$ $^{\ominus}$Cl

now you actually have a net negative charge ... this raises the energy of the HOMO, such that the $e^{\ominus}$s are more available to donate

neutral π-nucleophiles:





for

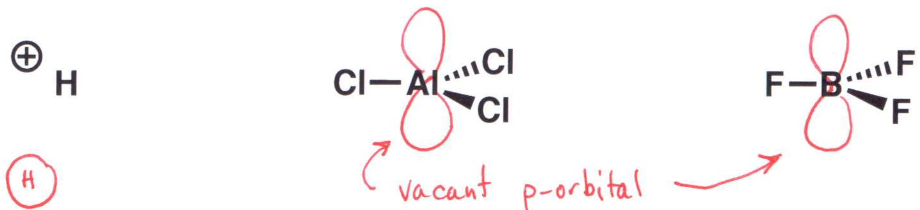
:C≡N

formal −1 charge on carbon. Carbon is less EN than N, the HOMO is higher. Nitriles are nucleophidic on carbon.

Electrophiles

- electrophiles are neutral or cationic species with low energy vacant or anti-bonding orbitals that can accept electrons

Protic and Lewis acids:



vacant 1s orbital

vacant p-orbital

Halides or other compounds with weak σ-bonds:

polarization can help, but it doesn't give the full story

poor orbital overlap

~~weak~~ weak bond

$Cl—CH_3$ ($\delta^{\ominus}$ Cl, $\delta^{\oplus}$ C) 81 kcal/mol

$Br—CH_3$ 68 kcal/mol

$I—CH_3$ 51 kcal/mol

$Br—Br$ 46 kcal/mol

to understand why alkyl halides are good electrophiles, we need to also consider orbitals

these bonds are hardly polarized at all?!

Bond strength matters...

atom	EN
C	2.6
F	4.0
Cl	3.2
Br	3.0
I	2.7
B	2.0
H	2.2