

# INDUCTIVE EFFECTS IN A COVALENT BOND

Chemical reactions take place as a result of giving, taking and/or sharing of electrons. So the different effects which influence the distribution of electrons in a covalent bond of an organic molecule are important for understanding the mechanism of the reactions the molecule undergoes. It is important to note that the driving force behind all of these so-called 'effects' is stability and energy minimization.

## Inductive Effect

A covalent single bond is made up of two paired electrons. But in cases when the atoms forming the bond differ in electronegativity (electronegative atoms love electrons) it results in a 'polarized' bond (which means the bonded electrons are shifted towards the more electronegative atom). So a C-N bond in  $\text{CH}_3\text{NH}_2$  (methylamine) would be polarized as follows:

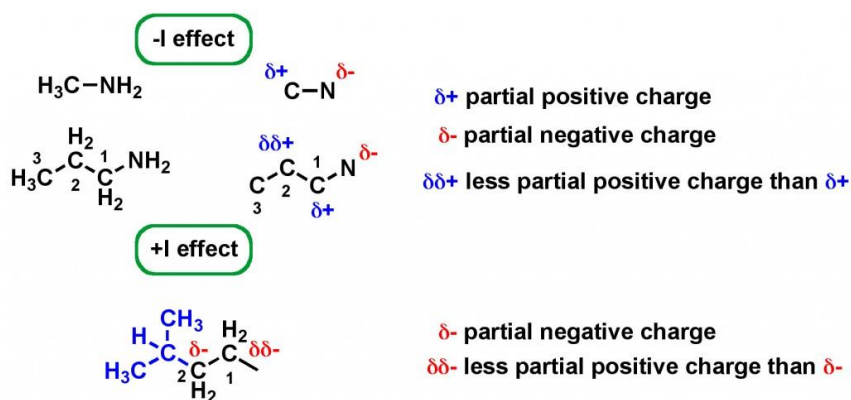


Figure 1. Inductive effects

$\delta^+\text{C}-\text{N}^{\delta-}$ , where  $\delta$  indicates partial charge, not full shift of charge like an ionic bond. So what basically happens is N pulls the bonded electrons towards it leaving the C slightly positive or electron deficient. Now if this C-N bond is a part of a bigger chain like in  $\text{C}^3\text{H}_3-\text{C}^2\text{H}_2-\text{C}^1\text{H}_2-\text{NH}_2$ , then due to this effect, the C next to the N is slightly positive charged. Being positive (electron deficient) it wants more electrons so it pulls the bonded pair of electrons from the C next to it ( $\text{C}^2$ ), which in turn becomes slightly positively charged as a result. Now the chain electron distribution looks like:

$-\text{C}-\text{C}^{\delta\delta+}-\text{C}^{\delta+}-\text{N}^{\delta-}$ , where  $\delta\delta+$  means less positively charged than  $\delta+$ . This relay of charge is called Inductive (I) effect. Since this case involves pulling of electrons which start the whole thing, it is termed -I effect. We can have +I effect as well which is illustrated as follows:

The  $(\text{CH}_3)_2\text{-CH}$  group also known as the isopropyl group is electron pushing; all alkyl groups can be considered to be electron donating. There is another effect called Hyperconjugation which has a role to play sometimes in the +I effect of alkyl groups, which we will discuss later. So C2 has excess electron density due to the electron pushing of the isopropyl group next to it. C2 having excess electrons push them to C1 making it partially negatively charged too. This effect does not carry beyond 2-3 carbon atoms.

The following list would be helpful for determining the magnitude of inductive effects in different molecules:

- Decreasing order of -I effect of these groups when attached to a molecule:



- Decreasing order of +I effect of these groups when attached to a molecule:



[stextbox id="info" caption="Why is this important?—An illustration"]

**The order of acidities of the molecules are as follows:**

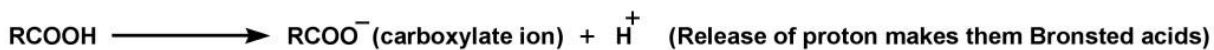


**Again the order of basicities of the molecules are as follows:**



**How can these be explained?**

Let us discuss the acids first. The reaction which makes those molecules acids is



So the more stable the carboxylate ion the easier this reaction will be, because remember all chemical processes try to go in the direction of stability. So if we compare the stabilities of the carboxylate ions from all the acids given we can tell which would readily give up the proton according to the reaction shown above.

$\text{CF}_3\text{-COO}^-$  has 3 fluorine (F) atoms which are highly electronegative and according to the list given above has a larger -I effect than Cl which in turn has a much larger -I effect than C as halogens are more

electronegative than C. Also  $\text{CF}_3\text{-COO}^-$  has two more electron withdrawing F atoms than  $\text{CH}_2\text{F-COO}^-$ , so the negative charge is better dissipated in  $\text{CF}_3\text{-COO}^-$  than  $\text{CH}_2\text{F-COO}^-$ . So  $\text{CF}_3\text{-COO}^-$  is more stable than  $\text{CH}_2\text{F-COO}^-$ .  $\text{CH}_2\text{F-COO}^-$  again is more stable than  $\text{CH}_2\text{Cl-COO}^-$ , simply because F has greater  $-I$  effect than Cl.  $\text{CH}_2\text{Cl-COO}^-$  is more stable than  $\text{CH}_3\text{COO}^-$  as the latter has no electronegative groups to pull the negative charge away. The stabilities of the carboxylates ions (better called 'conjugate bases' of the acids) are in the order :



As the more stable the carboxylate ions easier the deprotonation reaction, hence greater the acidity of the corresponding acid, the order of acidity is indeed :



For basicities of the amines, again inductive effect can be used to explain the order. The more C atoms the more is the  $+I$  effect (see the list provided). So  $(\text{C}_2\text{H}_5)_2\text{-NH}$  has the most electron density on the N atom due to the highest  $+I$  effect from the alkyl substituents. Across the series the number of substituents decrease and so does the  $+I$  effect thus gradually decreasing the electron density on the N atom which is the basic centre of the donating electrons thus acting as a Lewis base. The more the electron density on N, the better it can donate electrons, being the stronger base in the process. So  $(\text{C}_2\text{H}_5)_2\text{-N}$  is the strongest base and  $\text{NH}_3$  with no alkyl substitutions is the least basic. So the order



is justified.

Source : <http://padakshep.org/otp/subjects/chemistry/organic-chemistry/steric-electronic-effects/>