

An Iterative Method for Calculation of Group Electronegativities

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Received June 30, 1994[®]

A new method is presented for calculation of electronegativities of groups, or substituents, or substructures of molecules. The method combines the electron energies of the valence orbitals of each atom in the fragment. It is a simple calculation, well-suited to computers, which can provide the electronegativities of elements, atoms, substituents, substructures, and ionic groups. It is especially suited to calculation of the electronegativities of heterocyclic fragments.

INTRODUCTION

The concept of electronegativity, defined as the power of an atom or group of atoms to attract an electron, is widely used in chemistry and has been the subject of numerous attempts at systematic quantitation. The fundamental scale of electronegativity was first proposed by Pauling¹ whose scale was derived from thermochemical data. Subsequent workers established a number of specialized scales of electronegativity, including the Allred–Rochow scale² which is based upon covalent radii and effective charges, the Sanderson scale,^{3,4} which is based upon covalent radii, the Mulliken scale,⁵ which is based upon ionization potentials and electron affinities, and the Hinze scale,^{6,7} which is based upon orbital energies and effective charges.

Pauling's electronegativity scale was originally defined for atoms and as such is limited in its applicability to problems concerning organic structures. As a consequence, it was used as the basis of other concepts, such as bond electronegativity, orbital electronegativity, and group electronegativity. For the purposes of organic chemistry, group electronegativity is perhaps the most useful of these derived concepts.

A group can be a substituent or any part of a molecule. A substituent has a center atom, defined as the atom which is connected to the body of the molecule. Group electronegativity is defined as the electronegativity of the center atom of a substituent^{8–13} and this is affected by the neighbors of the central atom.

Electronegativity is an important parameter in molecular structure-activity relationships and such studies can benefit from a simple means of determining group electronegativity. Groups, or substituents, which are attached by one bond to a molecule are relatively easily managed, but it is also necessary to be able to handle groups which are attached to the remainder of the molecule by more than one bond; this is an extension which we reported previously¹⁴ of the notion of a "group". A "structural factor" was defined to deal with this situation. A structural factor can be a substituent or any part of a molecule and in this paper, the term is synonymous with "group". A structural factor may be attached to the remainder of the molecule through more than one atom; all such atoms are called center atoms. The electronegativity of the group is the set of electronegativities of the center atoms.

METHODS

The electronegativity scale which we propose to use is based on electron energies of the valence

$$X_g = \frac{-0.18 \sum_i n_i E_i}{\sum n^*} \quad (1)$$

orbitals and effective charges.⁸ This can be computed by eq 1 where E_i is the single electron energy of the orbital i of the center atom¹⁵ and n_i is the occupation of the E_i orbital. $\sum n^*$ is the sum of the effective valence electrons, which can be obtained from eq 2:

$$\sum n^* = n_\sigma + 0.7n_\pi + \left[\frac{(N+1)}{(N+2)} \right]^{0.29} n_n + 0.31n_{p-\pi} + 0.15 \sum_j (X_c - X_j) \quad (2)$$

Here, n_σ is the number of σ bonds of the center atom, n_π is the number of π bonds at the center atom, n_n is the number of lone pair electrons and $n_{p-\pi}$ is the number of $p-\pi$ conjugations that can be accepted by the center atom. X_c is the elemental electronegativity of the center atom (ignoring any neighboring atoms), X_j is the electronegativity of the neighboring atoms or groups j , and N is the atomic number of the center atom.

It can be seen that $\sum n^*$ will change as the atoms surrounding the center atom change and X_g will depend on the atoms surrounding the center atom. This is one of the advantages of this scale as compared to other electronegativity scales. The Sanderson scale, for example, is well defined and permits calculation of group electronegativities, atomic charges, and other properties based on the concept of electronegativity equalization,^{3,4,16–19} but in some cases, this concept may lead to results which are chemically unacceptable.²⁰ The main reason for this is that the effect upon the central atom of its neighbors has not been properly accounted for.

The elemental electronegativity of any atom can also be computed by means of eq 1. The only difference is that $\sum n^*$, the sum of the effective valence electrons, equates to the number of valence electrons in the atom. For consis-

[®] Abstract published in *Advance ACS Abstracts*, December 15, 1994.

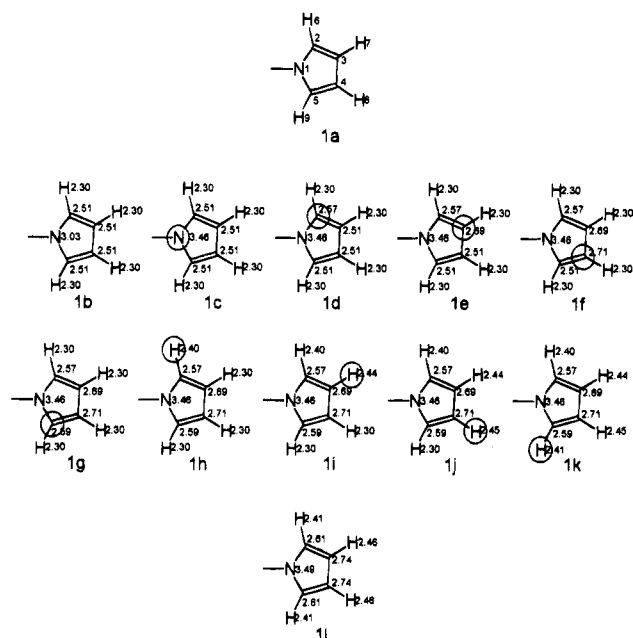
Table 1. Iterative Calculation of the Group Electronegativity of Pyrrolyl

iteration	Δ_{\max}	N ₁	C ₂	C ₃	C ₄	C ₅	H ₆	H ₇	H ₈	H ₉
1	0.431017	3.46402	2.57252	2.69438	2.70769	2.59259	2.39803	2.44462	2.44981	2.40558
2	0.041497	3.48217	2.60298	2.73588	2.73846	2.60822	2.40950	2.46090	2.46192	2.41149
3	0.005948	3.48770	2.60892	2.74183	2.74224	2.60978	2.41176	2.46325	2.46342	2.41208
4	0.000927	3.48860	2.60985	2.74262	2.74268	2.60997	2.41211	2.46356	2.46359	2.41216
5	0.000135	3.48874	2.60998	2.74272	2.74273	2.61000	2.41216	2.46360	2.46361	2.41216
6	0.000019	3.48876	2.61000	2.74274	2.74274	2.61000	2.41217	2.46361	2.46361	2.41217
7	0.000003	3.48876	2.61000	2.74274	2.74274	2.61000	2.41217	2.46361	2.46361	2.41217

tency, we assume that the elemental electronegativity of the hydrogen atom is 2.30.

Based upon the definition of electronegativity given by eq 1, an iterative method can be developed for the calculation of group electronegativities. As an example of the use of this method, the calculation of the electronegativity of the pyrrolyl group is described here. As a first step, an order number is assigned to each atom in the pyrrolyl group, as shown in **1a**. This is the order in which atomic electronegativities are calculated and it may be arbitrary. Next, each atom in the pyrrolyl group is labeled with its elemental electronegativity, as shown in **1b**. The elemental electronegativities can be obtained from eq 1, the value for hydrogen being set to 2.30⁸. These are the initial values for the iteration.

Let us consider the first iteration. According to the calculation order given in **1a**, the first atom to be considered will be the nitrogen. This nitrogen, circled in **1c**, happened to be the central atom of



the group and has an elemental electronegativity of 3.03. Recalculation of this value using eq 1 gives 3.46, and the atom is labeled with this new value in **1c**. In the next step C₂, marked with a circle in **1d**, is defined as the central atom. The new electronegativity for C₂ is 2.57, and this value is added to **1d**. In each calculation, the new values for the electronegativities of neighboring atoms (e.g., 3.46 for N is this case) are used. As the calculation proceeds from C₃ to H₉, structures **1e–k** are obtained. Each atom in the group is treated once as the central atom; and in each case a new value of the electronegativity is calculated using eq 1 and starting from the elemental electronegativity. In this way, the data in line 1 of Table 1 are obtained. These values, shown in **1k**, are the starting values for the next iteration.

Next, each new value is compared with its predecessor, and the largest discrepancy (e.g., 0.43 for N in iteration 1) is recorded. While this discrepancy is large, another iteration should be carried out using the X_c values obtained in the current step.

After the seven iterations shown in Table 1, the maximum discrepancy between two successive values is less than 10^{-5} which is defined here as convergence. At this iteration, the electronegativity of the nitrogen is 3.49, as noted on 1l. Since this nitrogen is the center of the pyrrolyl group, the electronegativity of the entire group is 3.49.

The ordering of the atoms in such a calculation may be arbitrary and the results will be the same. A computer program could use the topological connection table of a group and would use the atoms in the connection table in the order in which they appear. Such a program has been written in this laboratory. From the above example, it is easy to find that this iteration can handle groups with many center atoms.

RESULTS AND DISCUSSION

The electronegativities of over 300 commonly encountered groups have been calculated with this iterative method, and the results are given in Table 2. The results are chemically reasonable and compare well with published data.^{9–13} The iterative method provides electronegativities for elements, atoms, substituents, structural factors, and even ionic groups (none are shown in Table 2).

For the elements H, C, N, O, and F, the elemental electronegativities are found to be 2.30, 2.51, 3.03, 3.34, and 4.19, respectively, numbers which are very close to the values in Pauling's scale and which show the same rank ordering. The single bond electronegativities of the halogens F, Cl, Br, and I are 4.49, 3.10, 2.87, and 2.50, consistent with chemical intuition which places the $-F$ substituent as the most electronegative of the four groups.

The substituents $-\text{CH}_2\text{CH}_3$, $-\text{CH}=\text{CH}_2$, and $-\text{C}\equiv\text{CH}$ have group electronegativities of 2.48, 2.73, and 3.02, respectively. The increase in these values as one proceeds to the more unsaturated chains is consistent with the hybridization of the center atoms as sp^3 , sp^2 , and sp , respectively. The larger the s component in a hybridized orbital, the closer the electron cloud will be bound to the center atom and the higher the electronegativity will be, as is seen here. The method can also be used to calculate the group electronegativities of groups such as $=\text{CH}_2$ (2.70) and $\equiv\text{CH}$ (2.96).

Methods such as Sanderson's^{3,4} give the same group electronegativity for isomeric groups, but this method can distinguish between different isomeric possibilities. For the groups $-\text{CHFCH}_2\text{CH}_3$, $-\text{CH}_2\text{CHFCH}_3$, and $-\text{CH}_2\text{CH}_2\text{CH}_2\text{F}$ chemically reasonable group electronegativities of 2.68, 2.50, and 2.48, respectively, are obtained.

The iterative method is particularly well-suited to the calculation of the electronegativities of groups containing

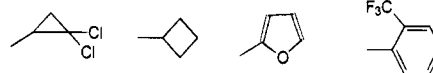
Table 2. Calculated Group Electronegativities

Group	X _g	Group	X _g	Group	X _g
>C<	2.507 (C)	-CH ₂ CH ₂ CH ₂ F	2.480 (C)	-CO-(n-C ₄ H ₉)	2.845 (C)
>C=	2.710 (C)	-CH ₂ CH ₂ N ₃	2.486 (C)	-CO-(n-C ₁₁ H ₂₃)	2.845 (C)
>CH-	2.494 (C)	-CH ₂ CH ₂ OH	2.486 (C)	-COC ₂ H ₅	2.845 (C)
>S<	2.508 (S)	-CH ₂ CH(CH ₃) ₂	2.478 (C)	-COC(CH ₃) ₂	2.847 (C)
>S=	2.643 (S)	-CH ₂ CH=CH ₂	2.502 (C)	-COC(CH ₃)=CH ₂	2.878 (C)
=C	2.949 (C)	-CH ₂ CHFCH ₃	2.500 (C)	-COCH ₂ C(CH ₃) ₂	2.846 (C)
=CH ₂	2.949 (C)	-CH ₂ Cl	2.537 (C)	-COCH ₂ CH ₂ Cl	2.846 (C)
=CH	2.955 (C)	-CH ₂ CN	2.540 (C)	-COCH ₂ CH ₂ COOBt	2.846 (C)
=N	3.577 (N)	-CH ₂ COCH ₃	2.514 (C)	-COCH ₂ CH(CH ₃) ₂	2.845 (C)
=C*	2.710 (C)	-CH ₂ COOC ₂ H ₅	2.502 (C)	-COCH ₂ CH=CH ₂	2.849 (C)
-CH-	2.703 (C)	-CH ₂ F	2.677 (C)	-COCH ₂ Cl	2.853 (C)
-N-	3.340 (N)	-CH ₂ N ₃	2.566 (C)	-COCH ₂ OPh	2.860 (C)
-(CH ₂) ₂ COOC ₂ H ₅	2.477 (C)	-CH ₂ NO ₂	2.590 (C)	-COCH ₂ Ph	2.849 (C)
-1,2,4-triazol-1-yl	3.565 (N)	-CH ₂ O-(n-C ₄ H ₉)	2.571 (C)	-COCH ₂	2.844 (C)
-1,2,4-triazol-5-yl	2.682 (C)	-CH ₂ OC ₂ H ₅	2.571 (C)	-COCH(CH ₃) ₂	2.846 (C)
-2,2,2-tri- <i>tert</i> -butyl-5-yl	2.514 (C)	-CH ₂ OCH ₂ CH ₂ OCH ₃	2.571 (C)	-COCH=CH ₂	2.878 (C)
-2,3-2Cl-Ph	2.749 (C)	-CH ₂ OCH ₂ Ph	2.571 (C)	-COCH=CHCH ₃	2.878 (C)
-2,6-2F-Ph	2.768 (C)	-CH ₂ OC ₂ H ₅	2.571 (C)	-COCH=CHPh	2.878 (C)
-2-Br-Ph	2.748 (C)	-CH ₂ OCOCH ₃	2.593 (C)	-CON(CH ₃) ₂	2.687 (C)
-2-CF ₃ -Ph	2.778 (C)	-CH ₂ OH	2.573 (C)	-CONH ₂	2.688 (C)
-2-CH ₃ -Ph	2.768 (C)	-CH ₂ OCOCH ₃	2.582 (C)	-CONHCH ₃	2.688 (C)
-2-Cl-Ph	2.751 (C)	-CH ₂ Ph	2.506 (C)	-CONHPh	2.717 (C)
-3-Br-Ph	2.765 (C)	-CH ₂ PO(OCH ₃) ₂	2.507 (C)	-COO(CH ₂) ₂ N(CH ₃) ₂	2.730 (C)
-3-CF ₃ -Ph	2.769 (C)	-CH ₂ SC ₂ H ₅	2.486 (C)	-COO-(i-C ₄ H ₉)	2.730 (C)
-3-CH ₃ -Ph	2.768 (C)	-CH ₂ SCN	2.519 (C)	-COOC ₂ H ₅	2.730 (C)
-3-Cl-Ph	2.765 (C)	-CH ₂ SO ₂ CH ₃	2.523 (C)	-COOC(CH ₃) ₂	2.730 (C)
-3-NO ₂ -Ph	2.770 (C)	-CH ₂	2.465 (C)	-COOCCH ₂ CH ₂ CH ₃	2.730 (C)
-3-OCH ₃ -Ph	2.766 (C)	-CH(CH ₃) ₂	2.490 (C)	-COOCCH ₂ CH ₂ OC ₂ H ₅	2.730 (C)
-4-CH ₃ -Ph	2.767 (C)	-CH(CH ₃)	2.485 (C)	-COOCCH ₂ CH=CH ₂	2.730 (C)
-4-Cl-Ph	2.767 (C)	-CH(CH ₃) ₂	2.490 (C)	-COOCCH ₂ Ph	2.731 (C)
-4-F-Ph	2.767 (C)	-CH(CH ₃)C ₂ H ₅	2.486 (C)	-COOCH ₃	2.730 (C)
-Br	2.874 (Br)	-CH(CH ₃)OC ₂ H ₅	2.579 (C)	-COOH	2.733 (C)
-C*	2.949 (C)	-CH(CH ₃)OC ₂ H ₅	2.579 (C)	-COON(CH ₃) ₂	2.736 (C)
-C-COCH ₃	3.017 (C)	-CH(i-C ₄ H ₉)	2.491 (C)	-COON=C(CH ₃) ₂	2.789 (C)
-C-CH	3.018 (C)	-CH(OCH ₃) ₂	2.680 (C)	-COOPH	2.756 (C)
-C ₂ H ₅	2.476 (C)	-CH=	2.703 (C)	-COPh	2.883 (C)
-C(CH ₃) ₂ C ₂ H ₅	2.733 (C)	-CH=C(CH ₃) ₂	2.729 (C)	-OSC ₂ H ₅	2.635 (C)
-C(S)NHCH ₃	2.588 (C)	-CH=CH ₂	2.728 (C)	-Ph	2.585 (C)
-C(CH ₃) ₂	2.499 (C)	-CH=CHCH ₂ CH ₃	2.729 (C)	- <i>gamma</i> -C ₂ H ₅	2.488 (C)
-C(CH ₃) ₂ C ₂ H ₅	2.496 (C)	-CH=CHCH ₂	2.729 (C)	- <i>gamma</i> -C ₂ H ₅	2.488 (C)
-C(CH ₃) ₂	2.495 (C)	-CH=CHCH=CH ₂	2.733 (C)	- <i>gamma</i> -C ₂ H ₅	2.488 (C)
-C(CH ₃) ₂ CH ₂	2.732 (C)	-CH=NOCH ₃	2.759 (C)	- <i>gamma</i> -C ₂ H ₅	2.488 (C)
-C(CH ₃) ₂ CHCH ₃	2.732 (C)	-CH=NOH	2.760 (C)	-F	4.495 (F)
-C(CH ₃) ₂ NOCH ₃	2.762 (C)	-CHBr-	2.528 (C)	-furan-2-yl	2.653 (C)
-C(CH ₃) ₂ NOH	2.762 (C)	-CHBr-n-C ₄ H ₉	2.525 (C)	-furan-3-yl	2.752 (C)
-CCl ₂	2.679 (C)	-CHCl ₂	2.608 (C)	H	2.300 (H)
-CCl=CH ₂	2.589 (C)	-CHCl=CH ₂	2.589 (C)	-I	2.497 (I)
-CCl=CHCl	2.575 (C)	-CHF-	2.917 (C)	-N<	3.133 (N)
-CF ₃	2.917 (C)	-CHFCH ₂ CH ₃	2.680 (C)	-N(C ₂ H ₅) ₂	3.039 (N)
-CF ₂ Cl	2.992 (C)	-CHFCl	2.752 (C)	-N(CH ₂ C≡CH)	3.091 (C)
-CF ₂	3.182 (C)	-CHO	2.845 (C)	-N(CH ₂ CH=CH ₂)	3.088 (N)
-CFCl ₂	2.826 (C)	-Cl	3.096 (Cl)	-N(CH ₃) ₂	3.037 (N)
-CH<	2.494 (C)	-CN	3.096 (C)	-N(CH ₃)	3.085 (N)
-CH-	2.480 (C)	-CO-	2.845 (C)	-N(CH ₃)CH ₂ CN	3.044 (N)
-CH ₂ -(4-NO ₂ -Ph)	2.506 (C)	-CO-(2,4-2Cl-Ph)	2.881 (C)	-N(CH ₃)SO ₂ CF ₃	3.088 (N)
-CH ₂ -(<i>gamma</i> -C ₂ H ₅ O)	2.498 (C)	-CO-(<i>gamma</i> -C ₂ H ₅)	2.847 (C)	-n-C ₄ H ₉	2.477 (C)
-CH ₂ Br	2.515 (C)	-CO-(<i>gamma</i> -C ₂ H ₅) ₂	2.847 (C)	-n-C ₄ H ₉	2.477 (C)
-CH ₂ C≡CH	2.532 (C)	-CO-(n-C ₄ H ₉)	2.845 (C)	-n-C ₄ H ₉	2.477 (C)
-CH ₂ CH ₂ Br	2.481 (C)	-CO-(n-C ₄ H ₉)	2.845 (C)	=P<	2.442 (P)
-n-C ₄ H ₉	2.477 (C)	-OCH(CH ₃) ₂	3.462 (O)	=S	2.703 (S)
-n-C ₄ H ₉	2.477 (C)	-OCH(CH ₃)C ₂ H ₅	3.462 (O)	=S<	2.643 (S)
-n-C ₄ H ₉	2.477 (C)	-OCH=CH ₂	3.562 (O)	-(2-Cl-Ph)-	2.751 (C)
-N-	3.340 (N)	-OCHF ₂	3.506 (O)	-(3-Cl-Ph)-	2.751 (C)
-N-C(CH ₃) ₂	3.315 (N)	-OCHO	3.673 (O)	-(CH ₂) ₁₁	2.477 (C)
-naphthalen-1-yl	2.772 (C)	-OCOCH ₃	3.673 (O)	-(CH ₂) ₁₁	2.477 (C)
-NCS	3.292 (N)	-OCONHCH ₃	3.659 (O)	-C≡C-	3.017 (C)
-NH ₂	3.050 (N)	-OH	3.481 (O)	-CH ₂ CH(CH ₃) ₂	2.479 (C)
-NH-	3.093 (N)	-OPh	3.666 (O)	-CH ₂ CH ₂ -	2.477 (C)
-NH-(i-C ₄ H ₉)	3.045 (N)	-OSO ₂ -(n-C ₄ H ₉)	3.503 (O)	-CH ₂ CH ₂ CH ₂ -	2.477 (C)
-NH-(i-C ₄ H ₉)	3.044 (N)	-OSO ₂ -(n-C ₄ H ₉)	3.503 (O)	-CH ₂ CH ₂ O ₂ -	2.486 (C)
-NH-(n-C ₄ H ₉)	3.044 (N)	-OSO ₂ C ₂ H ₅	3.503 (O)	-CH ₂ O-	2.578 (C)
-NHCH ₂	3.044 (N)	-OSO ₂ CH ₃	3.503 (O)	-CH=CCl-	2.713 (C)
-NHCH ₂ CN	3.051 (N)	-OSO ₂ Ph	3.506 (O)	-CH=CH-	2.729 (C)
-NHCH ₂	3.043 (N)	-Ph	2.767 (C)	-CO-(CH ₂) ₂ -CO-	2.845 (C)
-NHCOCH ₃	3.274 (N)	-PO(OC ₂ H ₅) ₂	2.651 (P)	-COCH ₂ -	2.846 (C)
-NHCONH ₂	3.258 (N)	-PO(OH) ₂	2.763 (P)	-CONH-	2.694 (C)
-NHCOOC ₂ H ₅	3.262 (N)	-Pyrazol-5-yl	2.625 (C)	-COO-	2.739 (C)
-NHCOOCH ₃	3.262 (N)	-S-	2.562 (S)	-COS-	2.635 (C)
-NHCOOCH(CH ₃) ₂	3.262 (N)	-S-(n-C ₄ H ₉)	2.564 (S)	-NHCONH-	3.259 (N)
-NHCONHPh	3.278 (N)	-S-(n-C ₄ H ₉)	2.564 (S)	-NHSO ₂ -	3.088 (N)
-NHENH ₂	3.095 (N)	-S-(n-C ₄ H ₉)	2.564 (S)	-OC(CH ₃) ₂ CH ₂ -	3.463 (O)
-NHPh	3.266 (N)	-SC ₂ H ₅	2.564 (S)	-OCH ₂ CH ₂ O-	3.463 (O)
-NO	3.194 (N)	-SC(CH ₃) ₂	2.565 (S)	-OCH(CH ₃)CH ₂ -	3.462 (O)
-NO ₂	3.626 (N)	-SCF ₂ CH ₂ F	2.598 (S)	-Ph-	2.768 (C)
-O-	3.532 (O)	-SCF ₃	2.613 (S)	-SO ₂ N(CH ₃)CH ₂ -	2.981 (S)
-O-(2-Cl-4-CF ₃ -Ph)	3.665 (O)	-SCH ₂ CH=CH ₂	2.566 (S)	-SO ₂ NH-	2.986 (S)
-O-(4-CH ₃ =Ph)	3.666 (O)	-SCH ₂ CN	2.568 (S)	=CHCH=	2.729 (C)
-O-(n-C ₄ H ₉)	3.461 (O)	-SCH ₂ COCH ₃	2.567 (S)	=PH(-O) ₂	2.652 (P)
-O-(n-C ₄ H ₉)	3.462 (O)	-SCH ₂ COOCH ₃	2.566 (S)		
-O-(n-C ₄ H ₉)	3.462 (O)	-SCH ₂ Ph	2.566 (S)		
-O-(n-C ₄ H ₉)	3.462 (O)	-SCH ₂	2.563 (S)		
-O-(n-C ₄ H ₉)	3.462 (O)	-SCH(CH ₃) ₂	2.565 (S)		
-O-(n-C ₄ H ₉)	3.462 (O)	-SCHF ₂	2.594 (S)		
-O-CCl=CHCl	3.648 (O)	-SCN	2.887 (S)		
-O-CF=CHCl	3.661 (O)	-SH	2.558 (S)		
-O-CF=CH	3.661 (O)	-Si(CH ₃) ₂	2.016 (Si)		
-O-CH=CCl ₂	3.659 (O)	-SO ₂ -	2.928 (S)		
-OC ₂ H ₅	3.461 (O)	-SO ₂ CF ₃	3.002 (S)		
-OCCl=CCl ₂	3.647 (O)	-SO ₂ CH ₂ CH ₂ CH ₃	2.934 (S)		
-OCF ₂ CH ₂ Cl	3.506 (O)	-SO ₂ CH ₂ CN	2.940 (S)		
-OCF ₂ CH ₂ I	3.505 (O)	-SO ₂ CH ₂	2.933 (S)		
-OCF ₂ CH ₂	3.505 (O)	-SO ₂ N(CH ₃) ₂	2.980 (S)		
-OCF ₂ CHCl ₂	3.507 (O)	-SO ₂ N(CH ₃)C ₂ H ₅	2.634 (S)		
-OCF ₂ CHF ₂	3.511 (O)	-SO ₂ NH ₂	2.982 (S)		
-OCF ₂	3.533 (O)	-SO ₂ Ph	2.961 (S)		
-OCF=CCl ₂	3.660 (O)	-SO-	2.732 (S)		
-OCH ₂ C≡CH	3.467 (O)	-SOCF ₂ CH ₂ F	2.630 (S)		
-OCH ₂ CCl=CCl ₂	3.462 (O)	-SOCH ₂	2.734 (S)		
-OCH ₂ CF ₃	3.469 (O)	=C<	2.710 (C)		
-OCH ₂ CH ₂ Cl	2.483 (C)	=C=	2.949 (C)		
-OCH ₂ CH ₂ F	3.464 (O)	=CH ₂	2.696 (C)		
-OCH ₂ CH ₂ OCH ₃	3.462 (O)	=CH-	2.703 (C)		
-OCH ₂ CH(CH ₃) ₂	3.462 (O)	=CHCH ₃	2.701 (C)		
-OCH ₂ CH=C(CH ₃) ₂	3.464 (O)	=CHPh	2.737 (C)		
-OCH ₂ CH=CH ₂	3.464 (O)	=N-	3.340 (N)		
-OCH ₂ CONH ₂	3.464 (O)	=NH	3.305 (N)		
-OCH ₂ OCH ₃	3.471 (O)	=NOCOCH ₃	3.034 (N)		
-OCH ₂ Ph	3.464 (O)	=NOH	3.014 (N)		
-OCH ₃	3.461 (O)	=O	3.729 (O)		

Table 3. Comparison of Electronegativities Calculated by Different Methods

group	X _g (present work)	X _g (Han ⁸)	Δ
-CH ₃	2.47	2.45	0.02
-C ₆ H ₅	2.77	2.74	0.03
-CF ₃	3.18	3.09	0.09
-CCl ₃	2.68	2.63	0.05
=O	3.73	3.73	0.00

cyclic moieties. The pyrrolyl group described above is an example of this, and others include the groups below whose electronegativities are 2.51, 2.49, 2.65, and 2.78, respectively.



Groups which possess more than one free bond fall into two categories. The first consists of those groups which have a single center atom which are treated as normal singly-bonded substituents. Examples include $-\text{CH}_2-$, $=\text{CH}-$, [\approx denotes a partial double bond], $-\text{CH}(\text{CH}_3)-$, $-\text{N}<$, which have electronegativities of 2.48, 2.70, 2.49, and 3.13, respectively. The second category consists of groups with more than one center atom, groups such as $-\text{C}(\text{O})\text{O}-$, and $=\text{PH}(\text{O})_2$. The atoms in parentheses here may also be regarded as center atoms, and the electronegativities in these cases are 2.74 (C), 3.67 (O) and 2.65 (P), 3.47 (O), 3.47 (O).

Han⁸ has published a series of group electronegativities, and these results are compared to ours in Table 3. The results are similar in many cases, but differ significantly in others. Thus, for $-\text{CF}_3$, electronegativities calculated by both methods differ by 0.09. This can be understood in terms of the physical model of the iterative method. When atoms are combined to form a substituent, the atomic charges are all redistributed. The iteration forces an equilibrium based upon the elemental electronegativities of the constituent atoms, and, in this way, the effects of the neighboring atoms on the center atom of the substituent are all accounted for.

CONCLUSION

An iterative method for the calculation of group electronegativities from the topological connectivities of substituents or substructures of molecules has been described. The method provides for full consideration of all atoms in groups. It can easily be built into computer programs and calculates the electronegativities of atoms, substituents, structural factors, and ionic groups. It is especially suitable for calculation of the electronegativities of heterocyclic substituents. Electronegativity values obtained by this method have been used in conjunction with other parameters, such as group quantum chemical parameters^{15,21} for structure-activity relationship studies. The iteration method gives the equilibrium distribution of charges in substituents and may be useful in calculation of the partial charges in molecules. A program ITERAEN, which runs on an IBM PC and compatibles,⁵ has been developed in this laboratory. It uses the topological connection table or the SMILES notation of groups²² to calculate their group electronegativities. It can handle elements, atoms, substituents, and ionic groups. Requests for copies of ITERAEN should be directed to Dr. Q. Xie.

ACKNOWLEDGMENT

This work was supported by the National Science Foundation of China. The authors would like to express their

gratitude to Dr. G. W. A. Milne, Editor of this Journal, for his assistance in the writing of this paper.

REFERENCES AND NOTES

- (1) Pauling, L.; Yost, D. M. The Additivity of the Energies of Normal Covalent Bonds. *Proc. Natl. Acad. Sci. U.S.A.* **1932**, *14*, 414–416.
- (2) Allred, L.; Rochow, E. A Scale of Electronegativity Based on Electrostatic Forces. *J. Inorg. Nucl. Chem.* **1958**, *5*, 264–268.
- (3) Sanderson, R. T. An Interpretation of Bond Lengths and a Classification of Bonds. *Science* **1951**, *114*, 670–672.
- (4) Sanderson, R. T. Electronegativity. I. Orbital Electronegativity of Neutral Atoms. *J. Chem. Ed.* **1952**, *29*, 540–546.
- (5) Mulliken, R. S. A New Electroaffinity Scale; Together with Data on Valence States and on Valence Ionization Potentials and Electron Affinities. *J. Chem. Phys.* **1934**, *2*, 782–793.
- (6) Hinze, J.; Jaffé, H. H. Electronegativity. 1. Orbital Electronegativity of Neutral Atoms. *J. Am. Chem. Soc.* **1962**, *84*, 540–546.
- (7) Hinze, J.; Whitehead, M. A.; Jaffé, H. H. Electronegativity. 2. Bond and Orbital Electronegativities. *J. Am. Chem. Soc.* **1963**, *85*, 148–154.
- (8) Han, C. R. The Calculation of the Ionic Group Electronegativities and Neutral Group Electronegativities. *Acta Chim. Sinica* **1990**, *48*, 627–631.
- (9) Inamoto, N.; Masuda, S. Revised Method for Calculation of Group Electronegativities. *Chem. Lett.* **1982**, 1003–1006.
- (10) Mullay, J. Atomic and Group Electronegativities. *J. Am. Chem. Soc.* **1984**, *106*, 5842–5847.
- (11) Mullay, J. Calculation of Group Electronegativities. *J. Am. Chem. Soc.* **1985**, *107*, 7271–7275.
- (12) Marriott, S.; Reynolds, W. F.; Taft, R. W.; Topsom, R. D. Substituent Electronegativity Parameters. *J. Org. Chem.* **1984**, *49*, 959–965.
- (13) Bratsch, S. G. A Group Electronegativity with Pauling Units. *J. Chem. Ed.* **1985**, *62*, 101–103.
- (14) Zhou, J.; Xie, Q.; Sun, D.; Xie, G.; Cao, L.; Xu, Z. Structure–Activity Relationships on Pesticides: A Development in Methodology and Its Software System. *J. Chem. Inf. Comput. Sci.* **1993**, *33*, 310–319.
- (15) Carlson, T. A. *Photoelectron and Auger Spectroscopy*; Plenum: New York, 1975; p 337.
- (16) Sanderson, R. T. *Chemical Periodicity*; Reinhold: New York, 1960.
- (17) Huheey, J. E. The Electronegativity of Groups. *J. Phys. Chem.* **1965**, *69*, 3284–3291.
- (18) Huheey, J. E. The Electronegativity of Multiply-Bonded Groups. *J. Phys. Chem.* **1966**, *70*, 2086–2092.
- (19) Stoklosa, H. J. Computer Program for the Calculation of Charge Distribution in Molecules. *J. Chem. Ed.* **1973**, *50*, 290.
- (20) Gasteiger, J.; Marsili, M. Iterative Partial Equalization of Orbital Electronegativity: A Rapid Access to Atomic Charges. *Tetrahedron* **1980**, *36*, 3219–3222.
- (21) Xie, Q.; Xie, G.; Sun, H.; Feng, J.; Zhou, J. *The Third China-Japan Drug Design and Development Symposium*; Beijing, China, 1993; p 53.
- (22) Weininger, D. SMILES, A Chemical Language and Information System. 1. Introduction to Methodology and Encoding Rules. *J. Chem. Inf. Comput. Sci.* **1988**, *28*, 31–36.

CI9400831