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Articles

Substituent Effects on Stability and Isomerization Energies of Isocyanides and Nitriles

Kuangsen Sung

Department of Chemistry, National Cheng Kung University, Tainan, Taiwan, ROC

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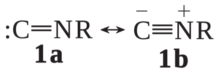
Homodesmotic reactions were designed to study substituent effects on stability and isomerization energies of isocyanides and nitriles. Good correlations between isocyanide and nitrile stabilization energies and Taft's dual-substituent parameters have been found. As to substituent effects of isocyanides, σ-donating N-substituents stabilize isocyanides while σ-accepting N-substituents destabilize them; π-donating N-substituents destabilize isocyanides while π-accepting N-substituents stabilize them. Regarding substituent effects of nitriles, σ-donating substituents stabilize nitriles while σ-accepting substituents destabilize them; π-donating substituents stabilize nitriles while π-accepting substituents destabilize them. Sensitivity of nitrile stability to substituent resonance and inductive effects is much less than that of isocyanides does. Isocyanide−nitrile isomerization energies have a good correlation with Taft's dual-substituent parameters; σ-donating substituents disfavor isomerization of isocyanides to nitriles while σ-accepting substituents favor it; π-donating substituents favor the isomerization while π-accepting substituents disfavor it. The isomerization of isocyanides to nitriles is exothermic, except for isocyanides with highly electropositive substituents such as Li, MgH, Na, AlH_2, and BeH.

Introduction

The substituent effects on structures and stabilities of a variety of organic compounds, such as ketenes,[1a−c] isocyanates,[1d] imines,[1d] allenes,[1c,2] cyclopropanes,[3] diazirines,[1c,4a,b] diazomethanes,[1c,4c−e] alkanes,[3c] alkenes,[3a,c,5] alkynes,[3a,5b] 1,3-dienes,[6a] cyclopropenes,[1c] carbonyl compounds,[5a,6b] and carbocations,[7] have been extensively studied by ab initio calculations in recent years. Recently we have studied substituent effects on stablity of ketenimines by ab initio calculations.[8] It has been found that σ-donating and π-accepting substituents stabilize ketenimines, while σ-accepting and π-donating substituents destabilize them.

Organic isocyanides were prepared as early as 19th century, but their exact structures could only be determined after modern spectroscopic methods were developed.[9] The isocyanides have two resonance structures, **1a**,**b**, and their characteristic IR absorption at ca. 2000 cm^{-1} indicates that **1b** resonance structure gives more contribution.[9] Compared with nitriles, their isomers, isocyanides are unusal and interesting in terms of structure and reactivity.[9,10] Isocyanide−nitrile rearrangement is not a new subject, but it has been becoming an interesting topic.[9,11−13] The isocyanide−nitrile rearrangement of aliphatic and aromatic isocyanides has little



$$:\mathrm{C{=}NR} \leftrightarrow \overset{-}{\mathrm{C}}{\equiv}\overset{+}{\mathrm{N}}\mathrm{R}$$

1a **1b**

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[1] (a) Tidwell, T. T. *Ketenes*; Wiley: New York, 1996. (b) Gong, L.; McAllister, M. A.; Tidwell, T. T. *J. Am. Chem. Soc.* **1991**, *113*, 6021. (c) McAllister, M. A.; Tidwell, T. T. *J. Org. Chem.* **1994**, *59*, 4506. (d) McAllister, M. A.; Tidwell, T. T. *J. Chem. Soc., Perkin Trans. 2* **1994**, 2239.

[2] (a) Furet, P.; Matcha, R. L.; Fuchs, R. *J. Phys. Chem.* **1986**, *90*, 5571. (b) Lambert, C.; Schleyer, P. v. R.; Wurthwein, E.-U. *J. Org. Chem.* **1993**, *58*, 6377.

[3] (a) Greenberg, A.; Stevenson, T. A. *J. Am. Chem. Soc.* **1985**, *107*, 3488. (b) Clark, T.; Spitznagel, G. W.; Klose, R.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1984**, *106*, 4412. (c) Wiberg, K. B.; Laidig, K. E. *J. Org. Chem.* **1992**, *57*, 5092. (d) Cremer, D.; Kraka, E. *J. Am. Chem. Soc.* **1985**, *107*, 3811.

[4] (a) Liang, C.; Allen, L. C. *J. Am. Chem. Soc.* **1991**, *113*, 1878. (b) Muller-Remmers, P. L.; Jug, K. *J. Am. Chem. Soc.* **1985**, *107*, 7275. (c) Goodman, J. M.; James, J. J.; Whiting, A. *J. Chem. Soc., Perkin Trans. 2* **1994**, 109. (d) Wang, F.; Winnik, M. A.; Peterson, M. P.; Csizmadia, I. G. *THEOCHEM* **1991**, *232*, 203. (e) Kahn, S. D.; Hehre, W. J.; Pople, J. A. *J. Am. Chem. Soc.* **1987**, *109*, 1871.

[5] (a) Heinrich, N.; Koch, W.; Frenking, G.; Schwarz, H. *J. Am. Chem. Soc.* **1986**, *108*, 593. (b) Dill, J. D.; Greenberg, A.; Liebman, J. F. *J. Am. Chem. Soc.* **1979**, *101*, 6814.

[6] (a) Wiberg, K. B.; Rosenberg, R. E. *J. Am. Chem. Soc.* **1990**, *112*, 1509. (b) Wiberg, K. B.; Hadad, C. M.; Rablen, P. R.; Cioslowski, J. *J. Am. Chem. Soc.* **1992**, *114*, 8644.

[7] White, J. C.; Cave, R. J.; Davidson, E. R. *J. Am. Chem. Soc.* **1988**, *110*, 6308.

[8] Sung, K. *J. Chem. Soc., Perkin Trans. 2*, in press.

[9] (a) Ruchardt, C.; Meier, M.; Haaf, K.; Pakusch, J.; Wolber, E. K. A.; Muller, B. *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 893. (b) Ugi, I. *Isocyanide Chemistry*; Academic Press: New York, 1971.

[10] (a) Rigby, J. H.; Laurent, S. *J. Org. Chem.* **1998**, *63*, 6742. (b) Shaabani, A.; Farrokhzad, F. *J. Chem. Res., Synop.* **1997**, 344. (c) Nguyen, P. T.; Palmer, W. S.; Woerpel, K. A. *J. Org. Chem.* **1999**, *64*, 1843. (d) Lentz, D. *Z. Naturforsch* **1992**, *47b*, 148. (e) Yavari, I.; Heydari, M.; Nori-Shargh, D. *J. Chem. Res., Synop.* **1994**, 384. (f) Meot-Ner, M.; Sieck, W.; Koretke, K. K.; Deakyne, C. A. *J. Am. Chem. Soc.* **1997**, *119*, 10430.

[11] (a) Sumathi, R.; Nguyen, M. T. *J. Phys. Chem. A* **1998**, *102*, 412. (b) Shen, D.; Pritchard, H. O. *J. Phys. Chem.* **1994**, *98*, 1743.

[12] (a) Casanova, J., Jr.; Werner, N. D.; Schuster, R. E. *J. Org. Chem.* **1966**, *31*, 3473. (b) Meier, M.; Muller, B.; Ruchardt, C. *J. Org. Chem.* **1987**, *52*, 648. (c) Kim, S. S.; Choi, W. J.; Zhu, Y.; Kim, J. H. *J. Org. Chem.* **1998**, *63*, 1185. (d) Meier, M.; Dogan, B.; Beckhaus, H.-D.; Ruchardt, C. *New J. Chem.* **1987**, *11*, 2.

[13] (a) Hertler, W. R.; Dixon, D. A.; Matthews, E. W.; Davidson, F.; Kitson, F. G. *J. Am. Chem. Soc.* **1987**, *109*, 6532. (b) Arnold, D. E. J.; Cradock, S.; Ebsworth, E. A. V.; Murdoch, J. D.; Rankin, D. W. H.; Skea, D. C. J.; Harris, R. K.; Kimber, B. J. *J. Chem. Soc., Dalton Trans.* **1981**, 1349. (c) Georgiou, K.; Legon, A. C. *J. Mol. Struct.* **1982**, *78*, 257.

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dependence of the reactivity on the structure of substrates, and they isomerize quantitatively at 210−250 °C with half-life of few hours.[12] However, this is not the case for isocyanides with heteroatom substituents, such as silyl isocyanides. The silyl isocyanides are reported to be in equilibrium with silyl nitriles at room temperature.[13] Therefore, structure−reactivity relationship for the isomerization appears ambiguous.

Hammett equation and its extensions (eq 1) have developed substituent effects on reaction rates (k) or

$$m \log(K/K_0) = m\Delta\Delta G = \log(k/k_0) = \Delta\Delta G^{\ddagger} = \rho\sigma = \rho_I\sigma_I + \rho_R\sigma_R \quad (1)$$

$$\Delta E \text{ (for isodesmic and homodesmotic reactions)} = \rho\sigma = \rho_I\sigma_I + \rho_R\sigma_R \quad (2)$$

equilibrium constants (K), and there exits a linear free-energy relationship between the two sets of effects.[14] It is confirmed that the extent ($\Delta\Delta G^{\ddagger}$) to which an activation free energy of a particular reaction is altered by adding a substituent is linearly related to the extent ($\Delta\Delta G$) to which an ionization free-energy change of benzoic acid is altered by putting the same substituent on the benzene ring.[14] Besides, the same series of changes in conditions affects the rate or equilibrium of a second reaction in exactly the same way as it affected the first except attenuated by an amount that depends on the second substrate.[14] The phenomena and concept have been applied to substituent effects on isodesmic and homodesmotic stabilization energies of cyclopropanes, ethylenes, acetylenes, benzenes, allenes, and ketenimines.[2a,3a,8] Since entropy changes of isodesmic and homodesmotic reactions are so small as to be negligible, it is reasonable that isodesmic and homodesmotic stabilization energies are directly correlated with substituent constants (σ) (eq 2). Both sign and magnitude of σ for a substituent are a measure of its capacity to perturb its environment electronically. Substituent constants σ_p and σ_m may involve both inductive and resonance contributions of substituents, but Taft's dual-substituent parameters (DSP) provide a good way to divide the substituent constant (σ) into σ_I for inductive contribution only and σ_R for resonance contribution only.[15] Therefore, in this article we study substituent effects on stability and isomerization energies of isocyanides and nitriles by ab initio calculations and by correlating the stabilization energies and isomerization energies with Taft's DSP.

The isodesmic reaction is one in which the total number of each type of bond is identical in the reactants and products, but there may be changes in the relationship of one bond to another.[16a] The homodesmotic reaction is defined as a reaction in which not only is the number of bonds of each type conserved but the number of carbon atoms with zero, one, two, or three hydrogen atoms is also conserved.[16b] The isodesmic and homodesmotic reactions are widely used in theoretical studies because errors in the energies of reactants and products are more likely to cancel, thereby allowing simple computational approaches to give accurate estimates of heats of reactions.[16c] Generally speaking, reactants are more stable than products if the isodesmic or homodesmotic reactions are endothermic; products are more stable than reactants if the reactions are exothermic.

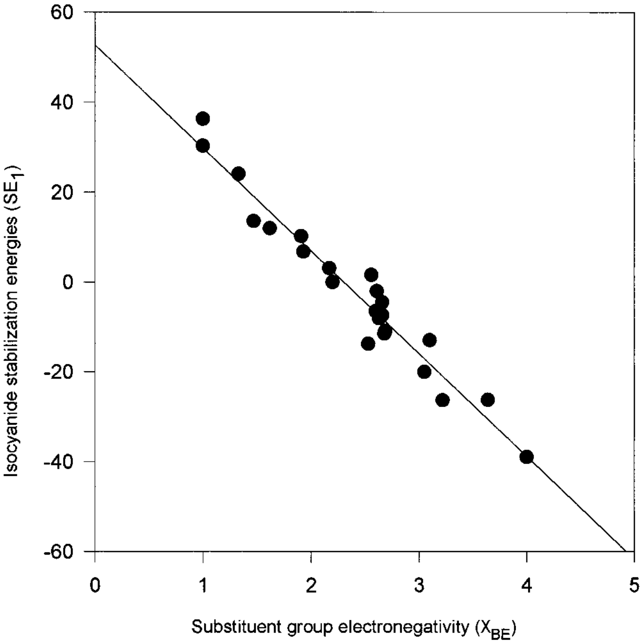

Figure 1.

Computation

All the calculations reported here were performed with the Gaussian94 program.[17] Geometry optimizations were carried out at the level of HF/6-31+G* without any symmetry restriction. After geometry optimizations were performed, analytically vibrational frequencies were calculated at the same level to determine the nature of the located stationary points. Thus, all the stationary points found were properly characterized by evaluation of the harmonic frequencies. Single point energies of the optimized structures were carried out by density functional theory (DFT) at level of B3LYP/6-311+G(2d,p)//HF/6-31+G*, and energies of all the stationary points were calculated at the same level with scaled zero-point vibrational energies included. The scaled factor of 0.8929 for zero-point vibrational energies is used according to the literature.[1b,c,16a]

The method of B3LYP/6-311+G(2d,p)//HF/3-21G* was reported to have 3.2 kcal/mol of mean absolute deviation and 3.0 kcal/mol of standard deviation in prediction of thermochemical quantities.[16a] In this article we used a better basis set (6-31+G*) to optimize all the compounds, so the mean absolute deviation and standard deviation are supposed to be smaller for our reults.

Results

Substituent effects on stability of isocyanides were studied with the homodesmotic reaction of eq 3, which

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(14) Isaacs, N. *Physical Organic Chemistry*, 2nd ed.; Longman Scientific & Technical: Essex, England, 1995.

(15) Ehrenson, S.; Brownlee, R. J. C.; Taft, R. W. *Prog. Phys. Org. Chem.* **1973**, *10*, 1. (b) Topsom, R. D. *Prog. Phys. Org. Chem.* **1976**, *12*, 1.

(16) (a) Foresman, J. B.; Frisch, A. *Exploring Chemistry with Electronic Structure Methods*, 2nd ed.; Gaussian, Inc.: Pittsburgh, PA, 1996. (b) George, P.; Trachtman, M.; Bock, C. W.; Brett, A. M. *Tetrahedron* **1976**, *32*, 317. (c) Hehre, W. J.; Radom, L.; Schleyer, P. v. R.; Pople, J. A. *Ab initio Molecular Orbital Theory*; Wiley: New York, 1986.

(17) Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Gill, P. M. W.; Johnson, B. G.; Robb, M. A.; Cheeseman, J. R.; Keith, T. A.; Pertersson, G. A.; Montgomery, J. A.; Raghavachari, K.; AlLaham, M. A.; Zakrzewski, V. G.; Ortiz, J. V.; Foresman, J. B.; Cioslowski, J.; Stefanov, B. B.; Nanayakkara, A.; Challacombe, M.; Peng, C. Y.; Ayala, P. Y.; Chen, W.; Wong, M. W.; Andres, J. L.; Replogle, E. S.; Gomperts, R.; Martin, R. L.; Fox, D. J.; Binkley, J. S.; Defrees, D. J.; Baker, J.; Stewart, J. P.; Head-Gordon, M.; Gonzales, C.; Pople, J. A. *Gaussian94, Revision D2*; Gaussian, Inc., Pittsburgh, PA, 1995.

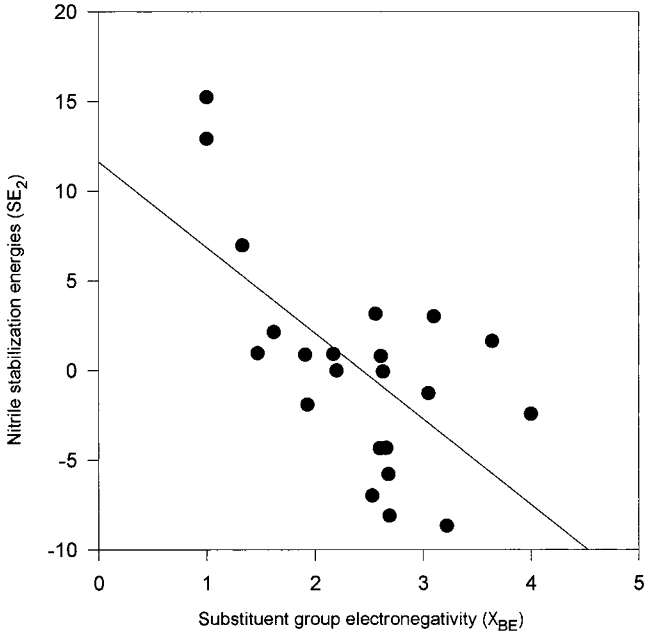

Figure 2.

$$:C{=}NR + H_2C{=}NH \xrightarrow{\Delta E = SE\ 1} :C{=}NH + H_2C{=}NR \quad (3)$$

measures the stabilizing effect of N-substituent, R, on isocyanides relative to the effect of the substituent on imines. The stabilization energies (SE$_1$) were correlated with Taft's DSP to study the influence of N-substituents on stability of isocyanides via inductive and resonance routes (Table 1). Two independent parameters (σ_I and σ_R) of Taft's DSP were taken from Charton's compendium.[18] The substituents were divided into two categories, π-donating and π-accepting substituents. In each category, values of σ_I and σ_R of the substituents were correlated with substituent stabilization energies by eq 4. In the category of π-donating substituents, eight

$$SE = \rho_I\sigma_I + \rho_R\sigma_R + \text{constant} \quad (4)$$

π donors (F, Cl, OH, NH$_2$, vinyl, ethynyl, CH$_3$, H):

$$SE_1 = (-51.29)\sigma_I + (20.62)\sigma_R - 5.14 \quad (5)$$

$$r^2 = 0.85 \quad \text{sey} = 6.57$$

π acceptors (CO$_2$H, CN, C(O)H, NO$_2$, CF$_3$, H):

$$SE_1 = (-33.10)\sigma_I + (2.93)\sigma_R + 1.36 \quad (6)$$

$$r^2 = 0.80 \quad \text{sey} = 5.08$$

substituents were chosen and the stabilization energies (SE$_1$) of isocyanides have a good correlation with the Taft's dual-substituent parameters with $r^2 = 0.85$ and sey = 6.57 (eq 5). Coefficients of σ_I and σ_R are −51.29 and +20.62, respectively. In the category of π-accepting substituents, six substituents were chosen and a correlation between the isocyanide stabilization energies (SE$_1$) and the Taft's dual-substituent parameters is good with $r^2 = 0.80$ and sey = 5.08 (eq 6). Coefficients of σ_I and σ_R are −33.10 and +2.93, respectively.

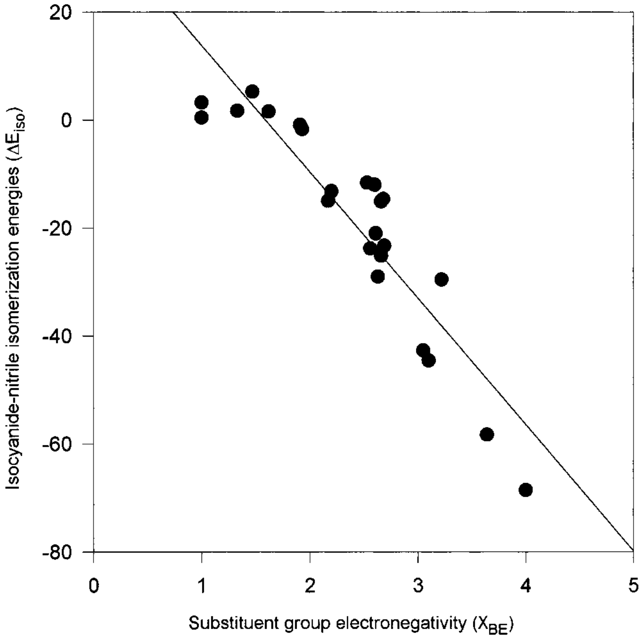

Figure 3.

Substituent effects on stability of nitriles were studied with a homodesmotic reaction of eq 7, which measures

$$RC{\equiv}N + HC{\equiv}CH \xrightarrow{\Delta E = SE_2} HC{\equiv}N + RC{\equiv}CH \quad (7)$$

the stabilizing effect of substituent, R, on nitriles relative to the effect of the substituent on alkynes. To study how inductive and resonance effects of the substituents influence on stability of nitriles, Taft's DSP was applied and correlated with the stabilization energies (SE$_2$) by eq 4 (Table 2).

In the category of π-donating substituents, seven substituents were chosen and the nitrile stabilization energies (SE$_2$) have a good correlation with Taft's dual-substituent parameters with $r^2 = 0.85$ and sey = 0.99 (eq 8). Coefficients of σ_I and σ_R are −9.33 and −4.32, respectively. In the category of π-accepting substituents, six substituents were chosen and a correlation between the nitrile stabilization energies (SE$_2$) and Taft's dual-substituent parameters is better with $r^2 = 0.99$ and sey = 0.34 (eq 9). Coefficients of σ_I and σ_R are −12.57 and −5.58, respectively.

π donors (F, Cl, OH, NH$_2$, vinyl, CH$_3$, H):

$$SE_2 = (-9.33)\sigma_I + (-4.32)\sigma_R + 1.21 \quad (8)$$

$$r^2 = 0.85 \quad \text{sey} = 0.99$$

π acceptors (CO$_2$H, CN, C(O)H, NO$_2$, CF$_3$, H):

$$SE_2 = (-12.57)\sigma_I + (-5.58)\sigma_R - 0.05 \quad (9)$$

$$r^2 = 0.99 \quad \text{sey} = 0.34$$

Substituent effects on isomerization energies (ΔE_{iso}) between isocyanides and nitriles (eq 10) were studied by correlating the isomerization energies with Taft's DSP (Table 3). In the category of π-donating substituents, eight substituents were chosen and the isomerization energies (ΔE_{iso}) have a good correlation with Taft's dual-substituent parameters with $r^2 = 0.89$ and sey = 7.69

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[18] Charton, M. *Prog. Phys. Org. Chem.* **1981**, *13*, 119.

Table 1. Calculated Energies (B3LYP/6-311+G(2d,p)//HF/6-31+G*) (Hartrees) for Isocyanides :C=NR and Imines $H_2C{=}NR$ and SE_1 (kcal/mol) for the Homodesmotic Reaction of Eq 3

R	χ_{BE}	σ_I	σ_R	*E*(isocyanides)	*E*(imines)	SE_1
Na	1.00			−255.177 62	−256.326 70	36.31
Li	1.00			−100.410 64	−101.569 24	30.34
MgH	1.33			−293.562 21	−294.730 79	24.08
BeH	1.47			−108.220 01	−109.405 32	13.58
AlH_2	1.62			−336.508 81	−337.696 67	11.98
SiH_3	1.91			−384.158 48	−385.349 09	10.25
BH_2	1.93			−118.882 75	120.100 55	6.81
PH_2	2.17			−435.392 34	−436.594 33	3.11
H	2.20	0	0	−93.418 85	−94.625 80	0
HSO_2	2.53			−642.047 21	−643.276 13	−13.79
CH_3	2.56	−0.01	−0.16	−132.716 92	−133.921 35	1.58
C(O)H	2.60	0.25	0.20	−206.757 38	−207.974 70	−6.51
$CH{=}CH_2$	2.61	0.11	−0.15	−170.803 62	−172.013 81	−2.03
SH	2.63			−491.613 48	−492.833 30	−8.08
ethynyl	2.66	0.29	−0.04	−169.558 91	−170.733 07	−4.52
CO_2H	2.66	0.30	0.11	−282.026 02	−283.244 75	−7.39
CF_3	2.68	0.40	0.11	−430.549 73	−431.774 90	−11.43
CN	2.69	0.57	0.08	−185.656 89	−186.881 18	−10.88
Cl	3.05	0.47	−0.25	−532.993 88	−554.229 80	−20.03
NH_2	3.10	0.17	−0.80	−148.732 65	−149.960 27	−12.97
NO_2	3.22	0.67	0.10	−297.914 76	−299.163 70	−26.35
OH	3.64	0.24	−0.62	−168.582 33	−169.831 09	−26.24
F	4.00	0.54	−0.48	−192.579 85	−193.848 99	−39.02

Table 2. Calculated Energies (B3LYP/6-311+G(2d,p)//HF/6-31+G*) (Hartrees) for Nitriles $RC{\equiv}N$ and Alkynes $RC{\equiv}CH$ and SE_2 (kcal/mol) for the Homodesmotic Reaction of Eq 7

R	χ_{BE}	σ_I	σ_R	*E*(nitriles)	*E*(alkynes)	SE_2
Na	1.00			−255.176 90	−239.044 27	15.23
Li	1.00			−100.405 42	−84.276 49	12.91
MgH	1.33			−293.559 48	−277.440 01	6.97
BeH	1.47			−108.211 61	−92.101 74	0.95
AlH_2	1.62			−336.506 33	−320.394 58	2.13
SiH_3	1.91			−384.165 32	−368.055 56	0.88
BH_2	1.93			−118.885 44	−102.780 11	−1.90
PH_2	2.17			−435.416 15	−419.306 32	0.92
H	2.20	0	0	−93.439 86	−77.331 50	0
HSO_2	2.53			−642.065 73	−625.968 49	−6.98
CH_3	2.56	−0.01	−0.16	−132.754 85	−116.641 46	3.16
C(O)H	2.60	0.25	0.20	−206.776 45	−190.675 03	−4.35
$CH{=}CH_2$	2.61	0.11	−0.15	−170.837 05	−154.727 42	0.80
SH	2.63			−491.659 71	−475.551 45	−0.06
CO_2H	2.66	0.30	0.11	−282.050 07	−265.948 60	−4.32
CF_3	2.68	0.40	0.11	−430.572 98	−414.473 83	−5.78
CN	2.69	0.57	0.08	−185.693 96	−169.598 51	−8.10
Cl	3.05	0.47	−0.25	−553.061 95	−536.955 59	−1.26
NH_2	3.10	0.17	−0.80	−148.803 68	−132.690 53	3.01
NO_2	3.22	0.67	0.10	−297.961 86	−281.867 30	−8.66
OH	3.64	0.24	−0.62	−168.675 22	−152.564 26	1.63
F	4.00	0.54	−0.48	−192.689 10	−176.584 59	−2.42

$$:C{=}NR \xrightarrow{\Delta E_{iso}} RC{\equiv}N \tag{10}$$

π donors (F, Cl, OH, NH_2, vinyl, ethynyl, CH_3, H):

$$\Delta E_{iso} = (-55.38)\sigma_I + (40.42)\sigma_R - 11.99 \tag{11}$$

$$r^2 = 0.89 \quad \text{sey} = 7.69$$

π acceptors (CO_2H, CN, C(O)H, NO_2, CF_3, H):

$$\Delta E_{iso} = (-27.84)\sigma_I + (41.89)\sigma_R - 11.97 \tag{12}$$

$$r^2 = 0.87 \quad \text{sey} = 3.18$$

(eq 11). Coefficients of σ_I and σ_R are −55.38 and +40.42, respectively. In the category of π-accepting substituents, six substituents were chosen and a good correlation between the isomerization energies (ΔE_{iso}) and Taft's dual-substituent parameters is found with $r^2 = 0.87$ and sey = 3.18 (eq 12). Coefficients of σ_I and σ_R are −27.84 and +41.89, respectively.

Substituent effects on the stability of isocyanides were also studied by correlating the isocyanide stabilization energies (SE_1) with substituent group electronegativity (χ_{BE}) (Figure 1). A good linear relationship ($SE_1 = -22.87\chi_{BE} + 52.73$) between them was found with a correlation coefficient of 0.95. The same method is applied to substituent effects on stability of nitriles, but a poor correlation ($SE_2 = -4.78\chi_{BE} + 11.64$) between the nitrile stabilization energies (SE_2) and substituent group electronegativity was found with a correlation coefficient of 0.40 (Figure 2). Substituent effects on the isomerization energies between isocyanides and nitriles were studied by correlating the isomerization energies (ΔE_{iso}) with substituent group electronegativity (Figure 3). A good linear relationship ($\Delta E_{iso} = -23.39\chi_{BE} + 37.18$) between them was found with a correlation coefficient of 0.84.

Discussion

As to isocyanides with π-donating N-substituents, a good correlation ($r^2 = 0.85$) between SE_1 and Taft's DSP was obtained (eq 5). The σ_I coefficient (−51.29) implies that σ-donating N-substituents stabilize isocyanides while σ-accepting N-substituents destabilize them. The σ_R coefficient (+20.62) implies that π-donating N-substituents destabilize isocyanides while π-accepting N-substituents stabilize them. As far as sensitivity of isocyanides stability to the π-donating substituents is concerned, electronegativity of substituents plays much more important role than their resonance effect does.

Regarding isocyanides with π-accepting N-substituents, there is also a good correlation ($r^2 = 0.80$) between SE_1 and Taft's DSP (eq 6). The σ_I coefficient is −33.10, indicating that σ-donating N-substituents stabilize isocyanides while σ-accepting N-substituents destabilize isocyanides. The σ_R coefficient is +2.93, indicating that π-donating N-substituents destabilize isocyanides while π-accepting N-substituents stabilize them. Sensitivity of

Table 3. Calculated Energies (B3LYP/6-311+G(2d,p)//HF/6-31+G*) (Hartrees) for Nitriles $RC\equiv N$ and Isocyanides $:C{=}NR$ and Their Isomerization Energies ΔE_{iso} (kcal/mol) of Eq 10

R	χ_{BE}	σ_I	σ_R	E(nitriles)	E(isocyanades)	ΔE_{iso}
Na	1.00			−255.176 90	−255.177 62	0.45
Li	1.00			−100.405 42	−100.410 64	3.28
MgH	1.33			−293.559 48	−293.562 21	1.71
BeH	1.47			−108.211 61	−108.220 01	5.27
AlH_2	1.62			−336.506 33	−336.508 81	1.56
SiH_3	1.91			−384.165 32	−384.158 48	−0.88
BH_2	1.93			−118.885 44	−118.882 75	−1.69
PH_2	2.17			−435.416 15	−435.392 34	−14.94
H	2.20	0	0	−93.439 86	−93.418 85	−13.18
HSO_2	2.53			−642.065 73	−642.047 21	−11.62
CH_3	2.56	−0.01	−0.16	−132.754 85	−132.716 92	−23.80
C(O)H	2.60	0.25	0.20	−206.776 45	−206.757 38	−11.97
$CH{=}CH_2$	2.61	0.11	−0.15	−170.837 05	−170.803 62	−20.98
SH	2.63			−491.659 71	−491.613 48	−29.01
ethynyl	2.66	0.29	−0.04	−169.599 00	−169.558 91	−25.16
CO_2H	2.66	0.30	0.11	−282.050 07	−282.026 02	−15.09
CF_3	2.68	0.40	0.11	−430.572 98	−430.549 73	−14.59
CN	2.69	0.57	0.08	−185.693 96	−185.656 89	−23.26
Cl	3.05	0.47	−0.25	−553.061 95	−532.993 88	−42.7
NH_2	3.10	0.17	−0.80	−148.803 68	−148.732 65	−44.57
NO_2	3.22	0.67	0.10	−297.961 86	−297.914 76	−29.56
OH	3.64	0.24	−0.62	−168.675 22	−168.582 33	−58.29
F	4.00	0.54	−0.48	−192.689 10	−192.579 85	−68.56

isocyanides stability to resonance effect of the π-accepting substituents is very small, compared to their inductive effect.

As to nitriles with π-donating substituents, a good correlation ($r^2 = 0.85$) between SE_2 and Taft's DSP was obtained (eq 8). The σ_I coefficient (−9.33) implies that σ-donating substituents stabilize nitriles while σ-accepting substituents destabilize them. The σ_R coefficient (−4.32) implies that π-donating substituents stabilize nitriles while π-accepting substituents destabilize them. Regarding nitriles with π-accepting substituents, there is also a good correlation ($r^2 = 0.99$) between SE_2 and Taft's DSP (eq 9). The σ_I coefficient is −12.57, indicating that σ-donating substituents stabilize nitriles while σ-accepting substituents destabilize them. The σ_R coefficient is −5.58, indicating that π-donating substituents stabilize nitriles while π-accepting substituents destabilize them. Nitrile stability does not depend on substituent inductive and resonance effects as much as isocyanide stability does. Sensitivity of nitrile stability to the substituent resonance effect is less important than that to the substituent inductive effect.

In most of cases, isomerization of isocyanides to nitriles is exothermic. However, isocyanides with electropositive substituents such as Li, MgH, Na, AlH_2, and BeH isomerize to nitriles endothermically. Only isocyanides with highly electropositive substituents such as Li, MgH, Na, AlH_2, and BeH are more stable than their corresponding nitriles. The isomerization energies of isocyanides with π-donating substituents have a good correlation ($r^2 = 0.89$) with Taft's DSP (eq 11). The σ_I coefficient is −55.38, indicating that σ-donating substituents disfavor isomerization of isocyanides to nitriles while σ-accepting substituents favor it. The σ_R coefficient is +40.42, indicating that π-donating substituents favor the isomerization while π-accepting substituents disfavor it. The isomerization energies of isocyanides with π-accepting substituents have a good correlation ($r^2 = 0.87$) with Taft's DSP (eq 12). The σ_I coefficient is −27.84, indicating that σ-donating substituents disfavor the isomerization while σ-accepting substituents favor it. The σ_R coefficient is +41.89, indicating that π-donating substituents favor the isomerization while π-accepting substituents disfavor it. The calculated isomerization energy for $CH_3CN/CNCH_3$ is 23.8 kcal/mol, which is in good agreement with an experimental value of 23.7 ± 0.1 kcal/mol.[19]

The stabilization energies (SE_1) of isocyanides have a good correlation ($SE_1 = -22.87\chi_{BE} + 52.73$) with substituent group electronegativity (χ_{BE}), indicating electropositive substituents stabilize isocyanides while electronegative substituents destabilize them. This is consistent with the results obtained by correlating the stabilization energies with Taft's DSP. There is a poor correlation ($SE_2 = -4.78\chi_{BE} + 11.64$) between the nitrile stabilization energies (SE_2) and substituent group electronegativity because of interruption of substituent resonance effect, and the correlation implies that electropositive substituents stabilize nitriles while electronegative substituents destabilize them. The result is the same as what we found by correlating the stabilization energies with Taft's DSP. The isomerization energies between isocyanides and nitriles have a good linear relationship ($\Delta E_{iso} = -23.39\chi_{BE} + 37.18$) with substituent group electronegativity, indicating electropositive substituents disfavor the isomerization of isocyanides to nitriles while electronegative substituents favor it. This result is consistent with what we found by correlating the isomerization energies with Taft's DSP.

Conclusions

The isocyanide stabilization energies (SE_1) have a good correlation with Taft's dual-substituent parameters. The σ-donating N-substituents stabilize isocyanides while the σ-accepting N-substituents destabilize them; the π-donating N-substituents destabilize isocyanides while the π-accepting N-substituents stabilize them.

The nitrile stabilization energies (SE_2) have a good correlation with the Taft's dual-substituent parameters too. The σ-donating substituents stabilize nitriles

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[19] Baghai-Vayjovee, M. H.; Collister, J. L.; Pritchard, H. O. *Can. J. Chem.* **1977**, *55*, 2634.

while the σ-accepting substituents destabilize them. The π-donating substituents stabilize nitriles while the π-accepting substituents destabilize them. The sensitivity of nitrile stability to the substituent resonance and inductive effects is much less than that of the isocyanides.

The isocyanide−nitrile isomerization energies (ΔE_{iso}) have a good correlation with Taft's dual-substituent parameters. The σ-donating substituents disfavor the isomerization while the σ-accepting substituents favor it; the π-donating substituents favor the isomerization while the π-accepting substituents disfavor it. The isomerization of isocyanides to nitriles is exothermic, except for isocyanides with highly electropositive substituents such as Li, MgH, Na, AlH_2, and BeH.

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