Z/E Selectivity on the Formation of 2,2'-Diacyl-9,9'-bifluorenylidenes Was Controlled by the Length of Acyl Side Chains

Masahiro Minabe,* Toru Oba, Masayuki Tanaka, Keiko Kanno, and Motohiro Tsubota
Department of Applied Chemistry, Faculty of Engineering, Utsunomiya University, Utsunomiya 321-8585

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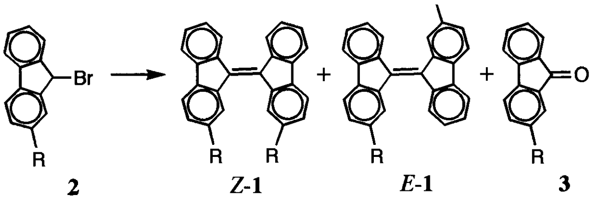
Reaction of 2-acetyl-9-bromofluorene with base afforded *Z*- and *E*-2,2'-diacetyl-9,9'-bifluorenylidene in a ratio of 30/70. A similar treatment of 2-stearoyl-9-bromofluorene gave the corresponding bifluorenylidene in a *Z*/*E* ratio of 90/10. The observed dependency of *Z*/*E* ratio on the chain length is attributable not to steric repulsion, but to intra- and/or inter-molecular attractive forces between the side chains.

Increasing attention has been drawn to 9,9'-bifluorenylidene (**1**, R = H) (Scheme 1) and its derivatives as a synthetic fragment of fullerene.[1] Among some of synthetic routes to obtain **1**, the simplest one is the reaction of 9-bromofluorene (**2**, R = H) with methanolic potassium hydroxide in acetone.[2] By the procedure, many 1,1'-, 2,2'-, 3,3'-, and 4,4'-disubstituted 9,9'-bifluorenylidenes were synthesized as geometrically isomeric mixtures.[3-5] The reaction of 2-methoxy- or 2-bromo-9,9-(ethylenedithio)fluorene with $W(CO)_6$ yielded *Z* and *E* isomers of **1** in a ratio of 1 : 1, while derivative of 2-(methoxycarbonyl)fluorene gave *Z* and *E* isomers in 2 : 1.[6] A mixture of *threo*- and *erythro*-2,2'-dimethyl-9-bromo-9,9'-bifluorenyl afforded only one of the corresponding geometrical isomers, 2,2'-dimethyl-9,9'-bifluorenylidene, by treatment with methanolic potassium hydroxide in acetone or by refluxing in *t*-butyl alcohol.[7]

The present communication concerns with the *Z*/*E* ratio on the formation of **1** (R = acyl) by the reaction of **2** with methanolic potassium hydroxide in acetone. This is a unique example that the *Z*/*E* selectivity is controlled by the length of acyl groups attached to the fluorene moiety.



Scheme 1.

Table 1 shows the results obtained by treatment of **2** (1.0 mmol) in acetone (30 mL) with potassium hydroxide in methanol (2 mL) for 1 h at room temperature. Upon dilution with water, the precipitates were collected and the amounts of isomeric **1** and fluorenone (**3**) were determined by ^{1}H NMR. The structures of the *Z* and *E* isomers were assigned by a combination of COSY, hetero COSY, and NOESY techniques.[8] Strong correlation was observed between H_1 (δ = 8.99) and $H_{8'}$ (δ = 8.37) in NOESY of *E*-**1** (R = stearoyl), while the corresponding correlation was not detected in the case of *Z*-**1**.

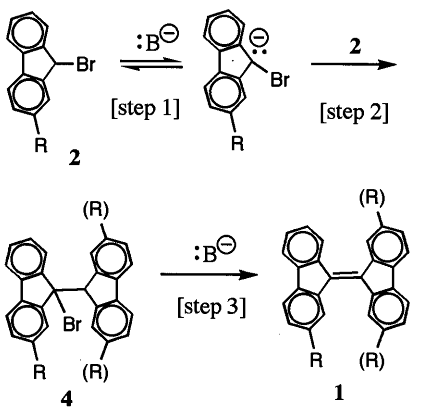
Table 1. *Z*/*E* Ratio of **1** from **2**

R	KOH^a	**1**		**3**
		Yield/%	*Z*/*E*	Yield/%
$COCH_3$	2.2	81	30 / 70	13
$COCH_3$	1.1	80	30 / 70	13
COC_8H_{17}	2.2	78	44 / 56	17
$COC_{17}H_{35}$	2.2	60	90 / 10	30
$COC_{17}H_{35}$	1.1	59	91 / 9	32

^{a}Molar equivalent to **2**.

The *E* isomer was a main product in the case that acetyl groups, having short alkyl moiety, were attached to fluorene nuclei. The *Z* isomer formed predominantly when stearoyl groups, having long alkyl moiety, were used as the side chain. Isomerization between *Z* and *E* isomers is presumed to be denied under the above reaction conditions,[9] as judged from the fact that the free energy of activation for the *Z*/*E* isomerization of **1** (R = methyl) has been accounted to be 104 kJ/mol.[10] This finding indicates that the *Z*/*E* selectivity is determined during the formation of **1** from **2**.

The mechanism of the reaction reported so far has, not via carbene,[2,11] been stated as follows.[5] The first step is the formation of the corresponding carbanion from **2** (step 1 in Scheme 2). The second is the nucleophilic attack of the carbanion to **2**, giving 9-bromo-9,9'-bifluorenyl (**4**). The third step is 1,2-elimination of hydrogen bromide from the intermediary **4** to yield **1**. The rate-determining step is step 2 in the presence of base (potassium *t*-butoxide) in *t*-butyl alcohol.



Scheme 2.

1 (R = acyl) in the present experiment may be formed via a route similar to that explained above. Because the formation of **4** was not recognized even at a lower temperature, the **4** formed was consumed immediately through the successive fast step 3. By-product, **3**, was obtained by an air-oxidation of **2**.[12]

Compound **4** (R = methyl) is reported to be a diastereomeric mixture, or the ratio of *threo*- and *erythro*-isomers is ca. 1/1.[7] We synthesized **4** separately by the reaction of the corresponding 9,9'-bifluorenyl with *N*-bromosuccinimide. Though separation of these isomers was failed at present, the presence of isomers (1 : 1) was confirmed by ^{1}H NMR in the case of **4** (R = stearoyl).[13] **4** (R = acetyl) afforded **1** in a *Z*/*E* ratio of 28 : 72, while **4** (R = stearoyl) gave **1** in 91 : 9, by reactions similar to the case that **2** was used as a starting material. These ratios are nearly the same as those obtained by direct conversions of **2** to **1**. This finding leads that step 3 (Scheme 2) is the product-determining step on the formation of **1** from **2**.

Rotation around the C_9-$C_{9'}$ bond of 2,2'-diacyl-9,9'-bifluorenyl cation should be permitted to give a stable conformer. *E* isomer is energetically stable in the case of the acetyl side chains; the side chains situate to decrease each other's steric repulsion. Stability of *Z* isomer increases with increasing length of the side chains (Table 1), though the carbonyl carbons are ca. 0.54 nm apart mutually.[14] We attribute it to increment of aggregative interactions between side chains. This view is supported by preliminary calculations that estimated enthalpy of formation (ΔH_f) and relative potential energy (E_{rel}) for the optimized structure of **1** using quantum mechanics program PM3 and molecular mechanics program MM+, respectively.[13] For the acetyl derivatives, *E* isomer (ΔH_f = 240 kJ/mol, E_{rel} = 94.5) was equally or slightly more stable than the corresponding *Z* isomer (ΔH_f = 240 kJ/mol, E_{rel} = 98.0). The results were ambivalent for the nonanoyl derivatives (*E*: ΔH_f = -62.5 kJ/mol, E_{rel} = 101; *Z*: ΔH_f = -79.1 kJ/mol, E_{rel} = 109), but *E* isomer (ΔH_f = -474 kJ/mol, E_{rel} = 117) was clearly less stable than the *Z* isomer (ΔH_f = -513 kJ/mol, E_{rel} = 110) for the stearoyl derivatives.

The aggregative interactions between the side chains are tentatively assumed to be van der Waals force between the alkyl groups and/or hydrogen bonds between both carbonyl oxygens through contaminating polar molecules such as water. Such intra- and/or inter-molecular interactions between two side chains may be advantageous over the interactions between the side chain and solvent molecules. The present study can be extended to a new regio-selective synthesis of the ‘fullerene fragments’. Precise examination on the *Z/E* selectivity is now under way.

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References and Notes

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8 Characteristic signals on ^{1}H NMR for *Z*-**1** (R = acetyl): δ 8.44 (2H, d, *J* = 7.8 Hz, H_8), 8.95 (2H, d, *J* = 1.5 Hz, H_1). *E*-**1** (R = acetyl): δ 8.37 (2H, d, *J* = 7.5 Hz, H_8), 9.00 (2H, d, *J* = 1.4 Hz, H_1).

9 Preliminary experiment showed that the isomerization was observed over 90 °C, giving finally Z/E mixture of 52/48 in both cases of acetyl and stearoyl derivatives.

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13 ^{1}H NMR signals of methylene protons adjacent to carbonyl groups for **4** (R = stearoyl): δ 2.71 - 2.72 (broad s), 2.73 (t, *J* = 7.5 Hz).

14 Molecular modelings were performed using a program package HyperChem version 5.1 (HyperCube Inc.) on a computer Dell Dimension XPS T-500. Molecular mechanics program MM+ and quantum mechanics program PM3 were employed without any modification of the parameters provided. A molecular structure was optimized initially by MM+, and then the structure obtained was optimized again by PM3. The alternate calculations with MM+/PM3 were continued until the energy of the model structure became almost unchanged. The obtained structure of *Z*-**1** (R = stearoyl), for example, showed two acyl chains stretched along one another (the nearest H-H distance, ca. 0.25 nm). Enthalpy of formation (ΔH_f) and relative potential energy (E_{rel}) were calculated for thus optimized structure by PM3 and MM+, respectively. The effects of solvents were omitted in all the calculations.