Organic Process Research & Development **1998**, *2,* 250–254

Practical Radical Additions under Mild Conditions Using 2,2′-Azobis(2,4-dimethyl-4-methoxyvaleronitrile) [V-70] as an Initiator

Yasuyuki Kita,*[,†] Kentoku Gotanda,[†] Kenji Murata,[†] Miki Suemura,[†] Atsunori Sano,[‡] Takahiro Yamaguchi,[‡]
Masahisa Oka,[‡] and Masato Matsugi[†]

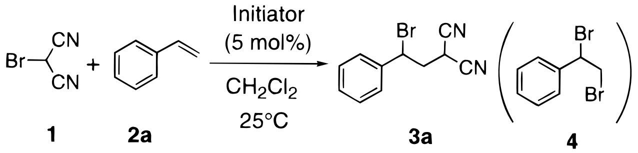
Graduate School of Pharmaceutical Sciences, Osaka University, 1-6, Yamada-oka, Suita, Osaka 565, Japan, and Tokyo Research Laboratories, Wako Pure Chemical Industries, Ltd., 1633, Matoba, Kawagoe, Saitama 350-11, Japan

Abstract:

Radical addition reactions of bromomalononitrile to various alkenes using 2,2′-azobis(2,4-dimethyl-4-methoxyvaleronitrile) (V-70) were examined. The advantages of V-70 which is an effective radical initiator at low temperature in contrast to the other azobis compounds are described. Especially V-70L (the low melting point diastereomer) was found to be the best radical initiator.

A formation of carbon−carbon bonds by radical addition reactions is one of the important tactics in organic synthesis.[1] In the radical addition reactions, 2,2′-azobisisobutyronitrile (AIBN) is commonly used as a radical initiator. For example, addition reactions of alkyl-substituted malononitrile radicals induced by AIBN to alkenes have been reported.[2] This approach, however, appears to be unsuitable to apply to heat-sensitive compounds, since AIBN requires generally elevated temperatures in the generation of the radicals.[3] Thus, addition of iodomalononitriles to oxygen-substituted alkenes such as ethyl 1-propenyl ether using AIBN was unsuccessful.[2a] On the other hand, photoinduced radical addition reactions are generally run at ambient temperatures. Additions of malononitrile radical induced by photoirradiation to alkenes are carried out successfully at room temperature,[4] but photochemical reactions are sometimes accompanied by difficulties such as practicability for large-scale productions. To evade these drawbacks, we intended to take advantage of 2,2′-azobis(2,4-dimethyl-4-methoxyvaleronitrile) [V-70][5] which is known as an effective initiator in the synthesis of polymers.[6] We expected that it would generate radical species at room temperature or below, because the half-life data of this compound indicated a species more unstable than AIBN.[7]

Table 1. **Addition of bromomalononitrile 1 to styrene 2a using various radical initiators**



entry	initiator	time (h)	yield (%) of **3a**
1	AIBN	24	no reaction[a]
2	BPO	24	no reaction
3	Et_3B	18	44
4	$h\nu$[b]	6	85
5	V-70	12	79

[a] If the reaction mixture was heated to generate the radical species, the dibromo adduct **4** was preferentially formed (33% yield). [b] A 400 W high-pressure mercury lamp was used through a Pyrex filter.

At first, radical addition reactions of bromomalononitrile (**1**) to styrene (**2a**) were examined at room temperature in the presence of various radical initiators, and the results are summarized in Table 1.[8] The reaction did not proceed at room temperature using AIBN and a typical peracid radical initiator such as benzoyl peroxide (BPO) (Table 1, entries 1

[†] Osaka University.

[‡] Wako Pure Chemical Industries, Ltd.

[1] For reviews, see: (a) Jaspers, C. P.; Curran, D. P.; Fevig, T. L. *Chem. Rev.* **1991**, *91*, 1237. (b) Porter, N. A.; Giese, B.; Curran, D. P. *Acc. Chem. Res.* **1991**, *24*, 296. (c) Curran, D. P. *Synthesis* **1988**, 417, 489. (d) Ramaiah, M. *Tetrahedron* **1987**, *43*, 3541. (e) Giese, B. *Radicals in Organic Synthesis: Formation of Carbon−Carbon Bonds*; Pergamon Press: Oxford, 1986.

[2] (a) Curran, D. P.; Thoma, G. *J. Am. Chem. Soc.* **1992**, *114*, 4436. (b) Curran, D. P.; Seong, C. M. *Tetrahedron* **1992**, *48*, 2157, 2175.

[3] For a review, see: Fossey, J.; Lefort, D.; Sorba, J. In *Free Radicals in Organic Chemistry*; John Wiley & Sons: New York, 1995; p 105.

[4] (a) Boldt, P.; Schulz, L. *Tetrahedron Lett*. **1966**, 1415. (b) Boldt, P.; Schulz, L.; Etzemuller, J. *Chem. Ber*. **1967**, *100*, 1281. (c) Boldt, P.; Thielecke, W.; Etzemuller, J. *Chem Ber*. **1969**, *102*, 4257. (d) Boldt, P.; Schulz, L.; Klinsmann, U.; Koster, H.; Thielecke, W. *Tetrahedron* **1970**, *26*, 3591. (e) Bartels, H. M.; Boldt, P. *Liebigs Ann. Chem*. **1981**, 40. (f) Bartels, H. M.; Boldt, P.; Schomburg, O. *Chem. Ber*. **1981**, *114*, 3997.

[5] 2,2′-Azobis(2,4-dimethyl-4-methoxyvaleronitrile) is commercially available from Wako Pure Chemical Industries Ltd., Japan, and the abbreviation in brackets [V-70] is its trade name. This compound is a mixture of diastereomeric isomers whose melting point are 58 and 107 °C and should be stored below −10 °C to prevent any decomposition. V-70 is stable in a refrigerator for a few months, and the pure V-70 can be easily obtained by the following procedure: V-70 (10 g, ca. 90% content) was added to dry acetone (20 mL) at −10 °C under stirring. The heterogeneous solution was stirred for 30 min at −10 °C. Collection of the crystalline precipitates afforded 6.2 g of pure V-70 (62%, >99% content).

[6] (a) Robertson, J. A. U.S. Pat. 2,586,995, 1952; *Chem. Abstr*. **1952**, *46*, 9579c. (b) Lim, D. *Collect. Czechoslov. Chem. Commun*. **1968**, *33*, 1122. (c) Shinohara, N.; Kudo, M.; Iwabuchi, M. Jpn. Kokai Tokkyo Koho JP 04,-66,588 [92,66,588] (Cl. C07F7/12), 02 Mar 1992, Appl. 90/172,449, 29 Jun 1990, 4 pp; *Chem. Abstr*. **1992**, *117*, 26799b. (d) Satsuka, H.; Takasu, Y. Jpn. Kokai Tokkyo Koho JP 06,172,232 [94,172,232] (Cl. C07C22/04), 21 Jun 1994, Appl. 92/329,416, 09 Dec 1992, 6 pp; *Chem. Abstr*. **1994**, *121*, 230457a. (e) Katsura, T.; Shiratani, H. Eur. Pat. Appl. EP 709,369 (Cl. C07C253/30), 1 May 1996, JP Appl. 94/289,079, 27 Oct 1994, 7 pp; *Chem. Abstr*. **1996**, *125*, 58121f.

[7] The temperature at which half of each initiator is decomposed in 10 h in toluene: AIBN, 65 °C; V-59, 67 °C; V-65, 51 °C; V-70, 30 °C; V-30, 104 °C; V-40, 88 °C; V-601, 66 °C. In 10 h in H_2O: VA-088, 88 °C; VA-086, 86 °C; VA-080, 80 °C; VA-082, 82 °C; V-50, 56 °C. In 10 h in MeOH: VA-061, 61 °C.

[8] Dichloromethane was used as the solvent in this reaction; however, the use of other solvents such as benzene or diethyl ether also gave the similar results. The yields in radical addition reactions of bromomalononitrile **1** to styrene **2a** using V-70 (5 mol %) were 73% (in benzene, rt, 24 h) and 76% (in diethyl ether, rt, 24 h).

S1083-6160(97)00059-5 CCC: $15.00

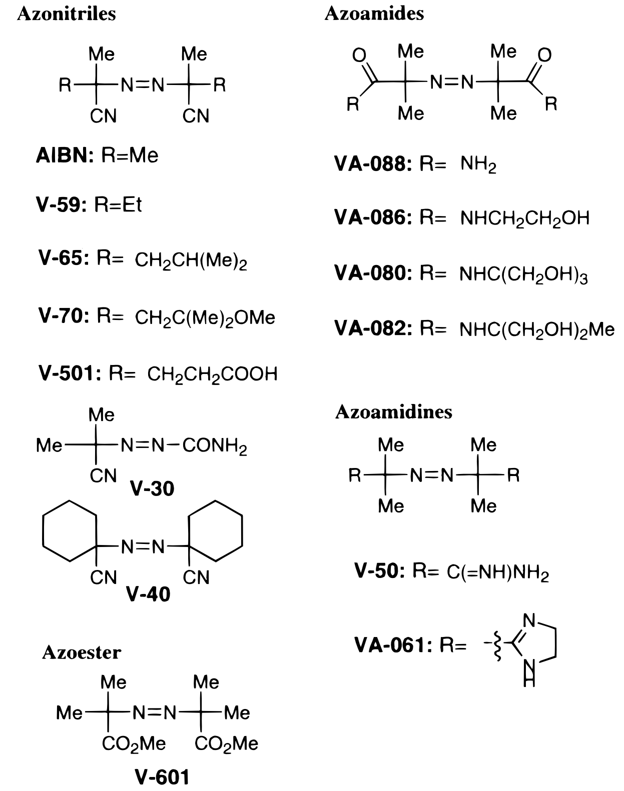


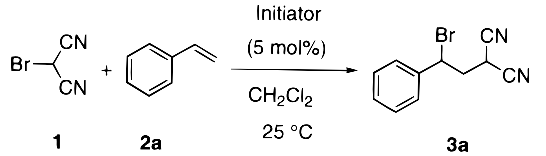
Figure 1. **Azo polymerization initiators.**

and 2). In the case of Et_3B, which is known as a useful radical initiator at low temperature,[9] the yield of the desired adduct (**3a**) was low, probably due to the decomposition of **1** (Table 1, entry 3). On the other hand, V-70 is quite effective for inducing the addition of **1** to **2a** at 25 °C to give **3a** in a satisfactory yield (Table 1, entry 5). The adduct **3a** was identical with an authentic sample which was obtained by the photoirradiation method[4] (Table 1, entry 4). An important point in this reaction is that the dibromo derivative **4** is preferentially formed, although the reaction mixture of **1** and **2a** is heated in refluxing benzene or toluene to generate the radical species in the presence of AIBN.

We then examined the radical addition reactions initiated by various azobis compounds listed in Figure 1,[10] which are known as commonly used radical initiators for the synthesis of polymers. The results are summarized in Table 2. We found that V-70 was a very effective radical initiator in this case, too, for the addition of **1** to **2a** at room temperature (25 °C) to give **3a**. The yields calculated by ^1H NMR are listed in Table 2.

Next, we examined the effect of the temperature when V-70 was used as the initiator in the reaction above (Table 3). Although the relative reaction rate was somewhat low, the adduct **3a** was also obtained with satisfactory yield of 89% at 0 °C (Table 3, entry 5). Furthermore, as a result of the examination of the essential amount of V-70, the adduct **3a** was also obtained with satisfactory yield of 80% even if a 1 mol % amount of V-70 was used (Table 4, entry 3).

Table 2. **Comparison of azobis-type initiators**



initiator	yield %	initiator	yield %
AIBN	no reaction	V-601	no reaction
V-59	45	VA-088	61
V-65	no reaction	VA-086	20
V-70	95	VA-080	3
V-501	68	VA-082	8
V-30	12	V-50	10
V-40	no reaction	VA-061	21

Table 3. **Effects of the temperature in the radical addition reactions of bromomalononitrile 1 to styrene 2a using V-70 (5 mol%)**

entry	temp. (°C)	time (h)	yield (%)
1	25	12	79
2	10	24	71
3	10	36	80
4	0	24	56
5	0	48	89

Table 4. **Effects of the ratio of V-70 in the radical addition reactions of bromomalononitrile 1 to styrene 2a**

entry	ratio of V-70 (mol %)	time (h)	yield (%)
1	10.0	6	71
2	5.0	12	79
3	1.0	48	80
4	none	48	no reaction

The generality of the additions of **1** to the other alkenes (**2b**−**j**) using V-70 was examined next. Consequently, target adducts **3b**−**j** were obtained with high yields under mild conditions such as room temperature in each case (Table 5).[11] It is noteworthy that the malononitrile radical cleanly reacts with oxygen-substituted alkenes (**2f**,**g**) using V-70 at room temperature (Table 5, entries 6 and 7), meanwhile the addition of methyl iodomalononitrile to oxygen-substituted alkenes using AIBN under the heated conditions was unsuccessful.[2]

In addition, the advantage of using V-70 than AIBN was observed in the reaction of **1a** and an activated oxygen-substituted styrene derivative **5** followed by alcoholysis (Table 6).[12] The use of V-70 predominantly gave the desired radical adduct **6** via a carbon−carbon bond forming reaction in good yield, although the use of AIBN predominantly gave the product **7** generated from the dibromo adduct (RCH-BrCHBrOMe).

Furthermore, this V-70 is a mixture of diastereomers which is composed by V-70H (high melting point) and

---

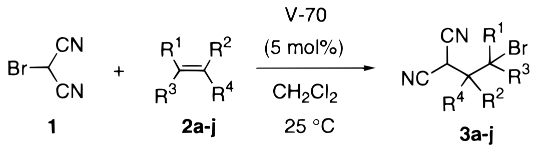
(9) For a review, see: Oshima, K.; Utimoto, K. *Synth. Org. Chem.* **1989**, *47*, 40.

(10) Other azobis compounds used in this paper are commercially available from Wako.

(11) Kita, Y.; Sano, A.; Yamaguchi, T.; Oka, M.; Gotanda, K.; Matsugi, M. *Tetrahedron Lett.* **1997**, *38*, 3549.

(12) Miwa, T.; Hitaka, T.; Akimoto, H. *J. Org. Chem.* **1993**, *58*, 1696.

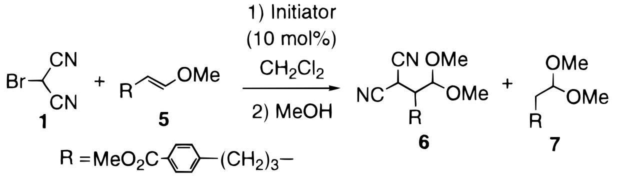
Table 5. **Additions of bromomalononitrile 1 to various alkenes 2 using V-70**



		alkene **2**				time (h)	yield of **3** (%)
entry		R^1	R^2	R^3	R^4		
1	**a**	Ph	H	H	H	12	79
2	**b**	Ph	H	H	Me	72	68
3	**c**	Me	Me	Me	H	12	81
4	**d**	Me	Me	Me	Me	12	84
5	**e**	$I(CH_2)_8$	H	H	H	24	78
6	**f**	OAc	H	H	H	24	76
7	**g**	OEt	H	H	H	24	72[a]
8	**h**	cyclopentene				24	88[b]
9	**i**	cyclohexene				24	90[c]
10	**j**	norbornene				24	89[d]

[a] Calculated by crude ^{1}H NMR. The molar ratios of the *trans*- to *cis*-isomer were 2.82[b], 1.02[c], 0.18[d].

Table 6. **Additions of bromomalononitrile 1 to 5**



entry	initiator	time (h)	temp. (°C)	combined yield of **6** and **7** (%)	ratio[a] **6**:**7**
1	V-70	2	25	80	55:45
2	AIBN	24	25	55	10:90

[a] Ratio was determined by ^{1}H NMR of crude products.

V-70L (low melting point). X-ray crystallography showed that V-70L was racemic and V-70H was meso (Figure 2). The separation of these epimers is readily possible through the difference of the solubility in diethyl ether.[13]

Although the kinetic study of the decomposition of each isomer of V-70 is reported,[14] the difference of activity for the radical addition reactions has not been apparent. Therefore, we examined the difference in the activity between V-70L and V-70H next. As a result, we found that V-70L is more active as a radical initiator than V-70H (Figure 3). This remarkable difference in activity was distinctly reflected in the isolated yields over the same time interval (Table 7).

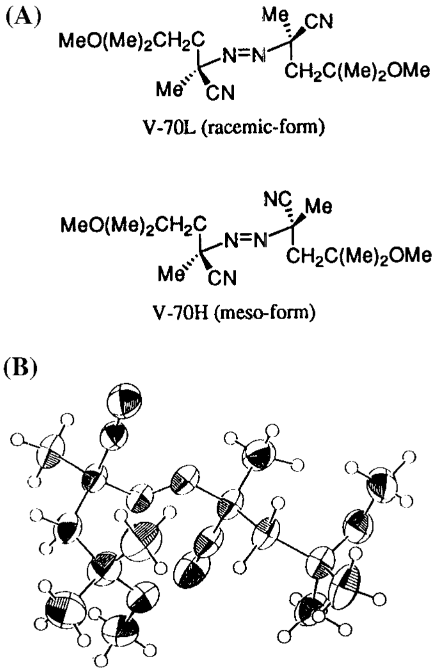


Figure 2. **(A) Structure of V-70L and V-70H. (B) X-ray crystallography of V-70L.**

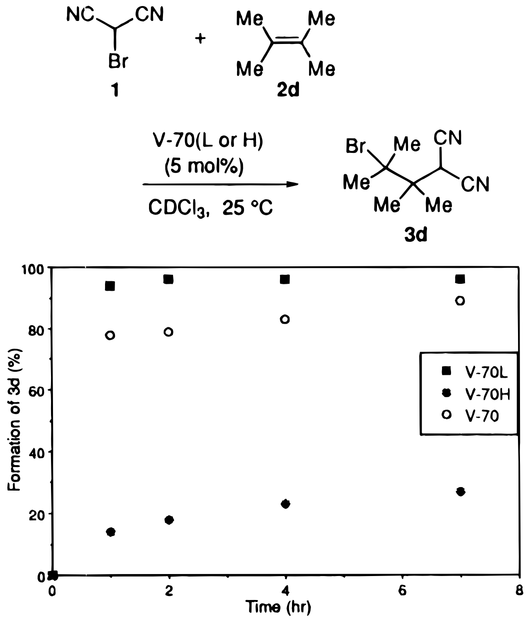


Figure 3. **Difference in the activity as the initiator between V-70L and V-70H.**

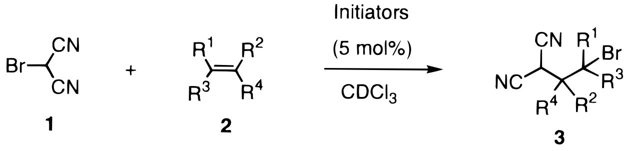
In conclusion, we clarified that V-70 has the highest activity as a radical initiator of the readily available azobis compounds listed in Figure 1 and that V-70 causes radical addition reactions at room temperature or below and affords a high yield of the addition products. By use of V-70, successful radical addition reactions were achieved which were did not take place with typical radical initiators such as AIBN or BPO. Furthermore, it has been apparent that the low melting point diastereomer V-70L has higher activity than another diastereomer (V-70H). It may be effectively applied to the compounds having labile functions which are sensitive to heat or basic or acidic conditions during the radical addition reactions. It is expected that some other useful reactions using the excellent initiator V-70 will be developed.

---

(13) V-70L: mp ca. 58 °C (dec.); ^{1}H NMR ($CDCl_3$) δ 1.29 (s, 12 H), 1.64 (s, 12 H), 2.26 (d, 2 H, $J = 11$ Hz), 2.42 (d, 2 H, $J = 11$ Hz), 3.21 (s, 6 H). V-70H: mp ca. 100 °C (dec.); ^{1}H NMR ($CDCl_3$) δ 1.20 (s, 6 H), 1.27 (s, 6 H), 1.69 (s, 6 H), 2.19 (d, 2 H, $J = 11$ Hz), 2.59 (d, 2 H, $J = 11$ Hz), 3.19 (s, 6 H).

(14) The kinetics of the decomposition of each isomer of V-70 were measured at 30−60 °C in several solvents: Palma, G.; Talamini, G.; Gasparini, P.; Busetti, V. *Chim. Ind. (Milan)* **1970**, *52* (11), 1116.

Table 7. **Comparison of the activity between diastereomers of V-70**



entry	initiators	alkene 2					temp. (°C)	time (h)	yield of 3 (%)[a]	
			R^1	R^2	R^3	R^4				
1	V-70	**2a**	Ph	H	H	H	25	24	**3a**	94
2							25	2		92
3							10	5		49
4	V-70L	**2a**	Ph	H	H	H	25	24	**3a**	92
5							25	2		93
6							10	5		62
7	V-70H	**2a**	Ph	H	H	H	25	24	**3a**	85
8							25	2		80
9							10	5		38
10	V-70L	**2d**	Me	Me	Me	Me	25	1	**3d**	95
11	V-70H	**2d**	Me	Me	Me	Me	25	1	**3d**	7
12	V-70L	**2i**	cyclohexene				25	4	**3i**	79[b]
13	V-70H	**2i**	cyclohexene				25	4	**3i**	49[b]
14	V-70L	**2j**	norbornene				25	4	**3j**	81[c]
15	V-70H	**2j**	norbornene				25	4	**3j**	41[c]

[a] Isolation yield by column chromatography. The molar ratios of *trans*- to *cis*-isomer were 1.17[b] and 0.18[c].

Experimental Section

Melting points are uncorrected. ^{1}H NMR spectra were measured in $CDCl_3$ on 200, 250, and 500 MHz spectrometers with $SiMe_4$ as the internal standard. E. Merck silica gel 60 (70−230 mesh ASTM) for column chromatography and E. Merck precoated TLC plates with silica gel F254 for preparative TLC (PLC) were used. Azobis compounds containing V-70 are commercially available from Wako Pure Chemical Ind. Ltd., Japan. Alkenes **2a**−**j** are commercially available from Aldrich Chemical Company. The known compounds **1** and **5** were prepared by the reported methods.[2,12]

Radical Adducts 3a−j, 6, and 7. *Typical Procedure*. A mixture of **1** (1.45 g, 10 mmol), **2a** (2.08 g, 20 mmol), and V-70 (308 mg, 5.0 mol %) in CH_2Cl_2 (10 mL) was stirred at room temperature in the dark. After 12 h, the mixture was concentrated in vacuo. The residue was recrystallized from 2-propanol (10 mL) to give **3a** in 79% yield. Compounds **3b**−**j**, **6**, and **7** were purified by flash column chromatography on silica gel [**3b** (hexane/AcOEt, 5:1), **3c** (hexane/AcOEt, 5:1), **3d** (hexane/AcOEt, 3:1), **3e** (hexane/AcOEt, 5:1), **3f** (hexane/AcOEt, 4:1), **3g** (hexane/AcOEt, 8:1), **3h** (hexane/AcOEt, 5:1), **3i** (hexane/AcOEt, 6:1), **3j** (hexane/AcOEt, 8:1)]. The physical data for **3a**−**j**, **6**, and **7** are summarized below.

*2-(2-Bromo-2-phenylethyl)malononitrile (**3a**):* (79% yield, as white crystals) mp 60.2−61.8 °C (lit.[4b] 60.5−61.0 °C); ^{1}H NMR ($CDCl_3$) δ 2.82 (m, 2 H), 4.01 (dd, 1 H, $J = 6, 10$ Hz), 5.08 (dd, 1 H, $J = 6, 10$ Hz), 7.41 (bs, 5 H); MS *m/z* (%) 250 ($M^+ + 2$, 2), 248 (M^+, 2), 104 (100); HRMS calcd for $C_{11}H_9{}^{79}BrN_2$ 247.9949, found 247.9948.

*2-(2-Bromo-1-methyl-2-phenylethyl)malononitrile (**3b**):* (68% yield, as a colorless oil); ^{1}H NMR ($CDCl_3$) δ 1.10 (d, 3 H, $J = 6$ Hz), 2.50 (m, 1 H), 3.32 (d, 1 H, $J = 9$ Hz), 4.87 (d, 1 H, $J = 9$ Hz), 7.34 (m, 5 H); IR (KBr) cm^{-1} 2240.

*2-(2-Bromo-1,2-dimethylpropyl)malononitrile (**3c**):* (81% yield, as white crystals); mp 40.5−41.9 °C (lit.[4b] 41.0−41.5 °C); ^{1}H NMR ($CDCl_3$) δ 1.43 (d, 3 H, $J = 7$ Hz), 1.82 (s, 3 H), 1.91 (s, 3 H), 2.59 (dq, 1 H, $J = 7, 2$ Hz), 4.59 (d, 1 H, $J = 2$ Hz).

*2-(2-Bromo-1,1,2-trimethylpropyl)malononitrile (**3d**):* (84% yield, as white crystals); mp 115.4−116.2 °C (lit.[4b] 117−117.5 °C); ^{1}H NMR ($CDCl_3$) δ 1.46 (s, 6 H), 1.95 (s, 6 H), 4.45 (s, 1 H).

*2-(2-Bromo-10-iododecyl)malononitrile (**3e**):* (78% yield, as white crystals); mp 43.5−45.5 °C; ^{1}H NMR ($CDCl_3$) δ 1.33 (m, 12 H), 1.90 (m, 4 H), 2.49 (m, 2 H), 4.10 (m, 1 H), 4.25 (dd, 1 H, $J = 4, 11$ Hz); IR (KBr) cm^{-1} 2245. Anal. Calcd for $C_{13}H_{20}BrIN_2$: C, 37.98; H, 4.90; N, 6.81. Found: C, 38.25; H, 4.84; N, 6.82.

*Acetic acid, 1-bromomethyl-2,2-dicyanoethyl ester (**3f**):* (76% yield, as a pale yellow oil); ^{1}H NMR ($CDCl_3$) δ 2.17 (s, 3 H), 2.86 (dd, 2 H, $J = 5, 7$ Hz), 4.15 (t, 1 H, $J = 7$ Hz), 6.77 (t, 1 H, $J = 5$ Hz); IR (KBr) cm^{-1} 2250, 1770.

*2-(2-Bromo-1-ethoxyethyl)malononitrile (**3g**):* (72% yield, as a pale yellow oil); ^{1}H NMR ($CDCl_3$) δ 1.24 (t, 3 H, $J = 7$ Hz), 2.30 (dd, 2 H, $J = 4, 7$ Hz), 3.56 (t, 1 H, $J = 7$ Hz), 3.99 (q, 2 H, $J = 7$ Hz), 4.70 (t, 1 H, $J = 4$ Hz); IR (KBr) cm^{-1} 2257.

*2-(2-Bromocyclopentyl)malononitrile (**3h**):* (88% yield, as a pale yellow oil); ^{1}H NMR ($CDCl_3$) δ 1.69−2.68 (m, 7 H), 3.95 (m, 74/100 H), 4.15 (d, $J = 4$ Hz) 4.62 (m, 26/100 H). Anal. Calcd for $C_8H_9BrN_2$: C, 45.10; H, 4.26; N, 13.15. Found: C, 45.33; H, 4.14; N, 13.43.

*2-(2-Bromocyclohexyl)malononitrile (**3i**):* (90% yield, as a pale yellow oil); ^{1}H NMR ($CDCl_3$) δ 1.34−2.52 (m, 9 H), 3.80 (m, 50/100 H), 3.94 (m, 50/100 H), 4.62 (d, 50/100 H, $J = 3$ Hz), 4.74 (m, 50/100 H); MS *m/z* (%) 228 ($M^+ + 2$, 3), 226 (M^+, 3), 147 (100); HRMS calcd for $C_9H_{11}{}^{79}BrN_2$ 226.0105, found 226.0109. Anal. Calcd for $C_9H_{11}BrN_2$: C, 47.60; H, 4.88; N, 12.34; Br, 35.18. Found: C, 47.61; H, 4.86; N, 12.27; Br, 35.08.

*2-(3-Bromobicyclo[2.2.1]hept-2-yl)malononitrile (**3j**):* (89% yield, as a pale yellow oil); ^{1}H NMR ($CDCl_3$) δ 1.23−2.69 (m, 9 H), 3.67 (d, 17/100 H, $J = 8$ Hz), 3.90 (d, 83/100 H, $J = 8$ Hz), 3.95 (m, 17/100 H); MS *m/z* (%) 240 ($M^+ + 2$, 1), 238 (M^+ , 1); HRMS calcd for $C_{10}H_{11}N_2{}^{79}Br$ 238.0105, found 238.0103. Anal. Calcd for $C_{10}H_{11}BrN_2$: C, 50.23; H, 4.64; N, 11.72; Br, 33.42. Found: C, 50.05; H, 4.55; N, 11.77; Br, 33.00.

*4-(4-(Dicyanomethyl)-5,5-dimethoxypentyl)benzoic acid methyl ester (**6**):* (a pale yellow oil); ^{1}H NMR ($CDCl_3$) δ 1.65−1.84 (m, 4 H), 2.26 (m, 1 H), 2.72−2.75 (m, 2 H), 3.39 (s, 3 H), 3.44 (s, 3 H), 3.90 (s, 3 H), 4.12 (d, 1 H, $J = 4$ Hz), 4.31 (d, 1 H, $J = 5$ Hz), 7.26 (d, 2 H, $J = 8$ Hz), 7.97 (d, 2 H, $J = 8$ Hz); IR (KBr) cm^{-1} 2255, 1720; MS *m/z* (%) 330 (M^+, 1), 266 (100); HRMS calcd for $C_{18}H_{22}N_2O_4$ 330.1579, found 330.1582. Anal. Calcd for $C_{18}H_{22}N_2O_4$: C, 65.44; H, 6.71; N, 8.45. Found: C, 65.08; H, 6.61; N, 8.40.

*4-(5,5-Dimethoxypentyl)benzoic acid methyl ester (**7**):* (a colorless oil); ^{1}H NMR ($CDCl_3$) δ 1.32−1.48 (m, 2 H), 1.57−1.72 (m, 4 H), 2.67 (t, 2 H, $J = 8$ Hz), 3.30 (s, 6 H), 3.89 (s, 3 H), 4.34 (t, 1 H, $J = 5$ Hz), 7.23 (d, 2 H, $J = 9$

Hz), 7.95 (d, 2 H, $J = 9$ Hz); IR (KBr) cm^{-1} 1721; HRMS calcd for $C_{15}H_{22}O_4$ 266.1518, found 266.1517.

Separation of the Diastereomers of V-70. *Typical Procedure*. V-70 (5.00 g) in Et_2O (25 mL) was stirred at 10 °C for 30 min to precipitate only V-70H (2.46 g; content of 100% from ^{1}H NMR). On the other hand, the filtrate, upon cooling to −10 °C for 2 days, gave crystallized V-70L (1.05 g; content of 100% from ^{1}H NMR).

Comparison of the Activity between the Diastereomers of V-70. *Typical Procedure*. A mixture of **1** (1 mmol), **2a** (1 mmol) and V-70L (5 mol %) in $CDCl_3$ (1 mL) was stirred at 25 °C for 2 h in the dark under a positive atmosphere of dry nitrogen. After a small amount of galvinoxyl was added, the mixture was concentrated in vacuo below room temperature. The purification by column chromatography on silica gel (eluent, AcOEt/hexane = 1/5) gave **3a** in 93% yield.

Supporting Information Available

Ortep representations and X-ray crystallographic details (5 pages). See any current masthead page for ordering information and Web access instructions.

Received for review November 28, 1997.

OP970059Z