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Single Electron Transfer Induced Elemental Steps in the Transformation of Iodomalonic Esters and Related CH-acids under Solid-liquid PTC Conditions. Preparation of Electrophilic Cyclopropanes

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Abstract: *Single electron transfer induced elemental steps have been shown to occur during the transformation of iodomalonic esters and related CH-acids to cyclopropane derivatives under solid-liquid phase transfer catalytic conditions. The iodo derivatives are formed from iodine and CH-acids "in situ", in the same pot in which the transformations to cyclopropane derivatives take place. A number of electrophilic cyclopropanes with a wide range of substituents have been synthetised by this route.*

Key-words: SET process, solid K_2CO_3 surface, phase transfer iodination, cyclopropanes.

Introduction

Cyclopropane derivatives activated by two electron-withdrawing geminal substituents (electrophilic cyclopropanes) are useful intermediates for the preparation of natural products[1] and pyrethroid type insecticides.[2] Most of the methods utilized for their synthesis start from olefins and substituted malonic acid derivatives such as bromomalonic esters in the presence of copper (II)-salts,[3] dibromomalonic esters in the presence of copper or copper(I)-salts,[4] bromomalononitrile,[5] chloromalonic ester generated "in situ" from malonic ester with copper(II)-chloride[6] or diazomalonic esters.[2,7] The reactions of bromomalononitrile,[5] bromoma-

lonic esters[3a] or chloromalonic ester in the presence of base and copper salts[6] have been shown to proceed by a radical type chain process, while diazomalonic acid derivatives are well known to decompose to give nitrogen and carbene type intermediates which are then trapped by an olefin.[7]

No data have been found in the literature on the behaviour of the iodomalonic esters and related iodo-substituted CH-acids in the presence of base and olefins and there are no good procedures for their preparation. A tedious preparation of dimethyl iodomalonate has recently been published[8] and together with the well characterized μ-monoalkyl iodomalonic esters it is widely used in atom transfer reactions.[9]

Results and Discussion

In the course of a programme of work aimed at studying phase transfer catalytic reactions we brought together diethyl malonate with iodine in a hot toluene solution in the presence of solid potassium carbonate and a lipophilic quaternary ammonium salt, usually tricaprylmethylammonium chloride (TCMC, Aliquat®) (Fig. 1).

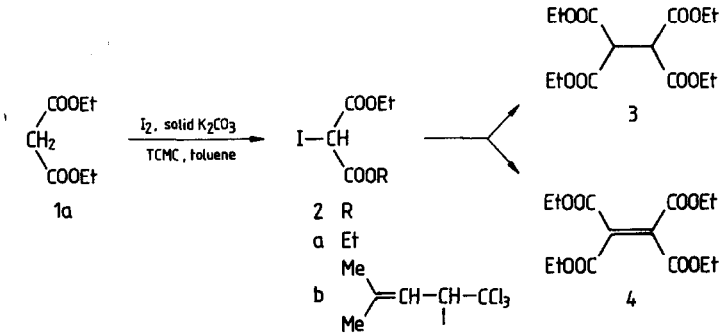


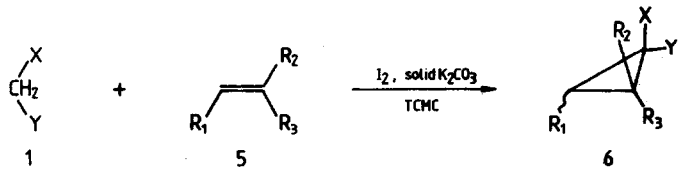
Fig. 1

A mixture of ethane- and ethylenetetracarboxylic acid ester[11] (**3** and **4**) was formed in good yield.[10] The ratio of the two compounds depends on the reaction conditions but mainly on the ratio of iodine to malonic ester. The formation of the iodomalonic ester as an intermediate in the reaction was demonstrated by GC-MS, as the very sensitive iodomalonic ester sample[8] was always contaminated by **3**, **4** and starting ester **1**.

In the presence of an olefin the direction of the above reaction changes. Substituted cyclopropane derivatives **6** are formed[10a] in low to fair yield if the malonic acid derivatives, dissolved in an aprotic solvent, are added dropwise to the warm, and stirred solution of the olefin in the same solvent containing two moles of dry, solid K_2CO_3, a catalytic amount of a lipophilic quaternary ammonium salt and one mole of iodine per mole of malonic ester (Fig. 2).

The method has been applied successfully to other CH-acids, although the yields are only moderate (Fig. 2).

If the CH-acid moiety is incorporated into the side chain of an olefin at a favorable position, as in **7**, an intramolecular reaction occurs, resulting in the formation of derivatives **8** having the lactone ring and the X group on the opposite side of the cyclopropane ring (Fig. 3).

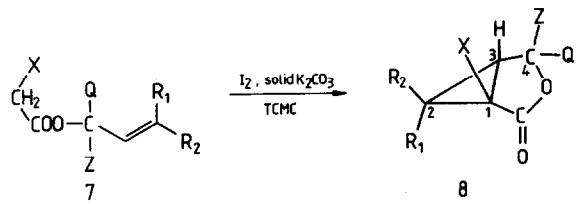


1 5 6

a X=Y=COOEt
b X=Y=CN

	R_1	R_2	R_3	X	Y
a	Me_2C=CH−	Me	Me	CN	CN
b	Cl_2C=CH−	Me	Me	COOEt	COOEt
c	Cl_2C=CH−	Me	Me	CN	CN
d	H	H	Ph	CN	CN
e	H	Me	Ph	CN	CN
f	H	Bu	H	COOEt	COOEt

Fig. 2



7 8

7,8	X	Q	Z	R_1	R_2
a	COOMe	CCl_3	H	Me	Me
b	COOEt	CCl_3	H	Me	Me
c	COOEt	H	H	H	H
d	$COCH_3$	CCl_3	H	Me	Me
e	COOEt	H	H	H	Me
f	COOEt	H	H	Me	H
g	COOEt	Me	Me	H	H
h	CN	CCl_3	H	Me	Me

Fig. 3

The compounds 7**a-c**, **e-g** were obtained from commercially available allylic alcohol derivatives by reaction with malonic ester chloride in the presence of 4-dimethylamino-pyridine, while 7**d** was prepared from 1,1,1-trichloro-4-methyl-pent-3-en-2-ol[2a] with diketene-acetone compound in the presence of p-toluenesulphonic acid catalyst.[12] The ring formation reaction leading from **7** to **8** goes smoothly and in high yield if the solution of **7** is added dropwise to the stirred mixture of K_2CO_3, iodine and phase transfer catalyst. Compounds so formed, except **8b**, are new, versatile starting materials for the stereoselective preparation of cis-, or trans-1,2-disubstituted cyclopropane derivatives. Lactone **8b** has already been prepared by a more tedious route[2a] and used for the stereoselective formation of the cis-disubstituted cyclopropane moiety as in the effective insecticide, deltamethrin.[2b]

To avoid the high steric interference between the methyl and the trichloromethyl groups, only the isomer **8b** having the trichloromethyl group in the exo position is formed (Fig. 4).

In the reaction of esters **7e** or **7f** which are obtained from E- and Z-crotyl alcohol, respectively, the same diastereomeric mixture of **8e** and **8f** is formed from both starting materials in a molar ratio of 60:40 with the exo-methyl isomer **8e** dominating. Structure elucidation of the endo (**8f**) and exo (**8e**) isomers was achieved by ^{1}H- and ^{13}C-NMR spectroscopy. The characterization data for these isomers are summarized in Table 1.

exo-CCl_3 **8b** endo-CCl_3

Fig. 4

Table 1. ^{1}H and ^{13}C Chemical Shifts (ppm) and J(H,H) Coupling Constants (Hz) of **8a**, **8e** and **8f** ($CDCl_3$, 400 MHz)

	8a	**8e**	**8f**
Me_{endo}-2	1.32	-	1.24
Me_{exo}-2	1.30	1.26	-
H_{endo}-2	-	1.63	-
H_{exo}-2	-	-	2.27
H-3	2.77	2.49	2.69
H_{endo}-4	4.54	4.13	4.06
H_{exo}-4	-	4.24	4.37
J(H-3,H_{endo}-4)	0	0	1.0
J(H-3,H_{exo}-4)	-	4.8	5.3
C-1	40.6	34.6	34.8
C-2	32.4	29.1	25.7
C-3	37.4	31.0	32.4
C-4	82.7	67.0	63.5
C=O	164.7	165.0	167.0
	167.2	170.7	169.1
Me_{endo}-2	16.4	-	7.3
Me_{exo}-2	20.9	11.6	-

For differentation of the **8e** and **8f** isomers, the ^{3}J(H-2,H-3) values proved to be useful. Considering the known[13] relationship $^3J(H,H_{cis}) > {}^3J(H,H_{trans})$ for cyclopropane derivatives it follows from the corresponding 5.0 Hz (**8e**) and 8.2 Hz (**8f**) coupling constants that the former is the exo- and the latter is the endo isomer.

Comparing the chemical shifts of the H-2 protons in **8e** (δ 1.63) and **8f** (δ 2.27), the steric proximity of the ester group results in a strong downfield shift. The ^{13}C spectra give further support for the identification of the exo and endo isomers. In **8f** the steric proximity of the Me-2 and CH_2O groups results in upfield shifts of these carbons (δ 7.3 and δ 63.5) compared with the chemical shifts measured for **8e** (δ 11.6 and δ 67.0).

Mechanism

A possible mechanism for the reaction[14] is shown in Fig. 5.

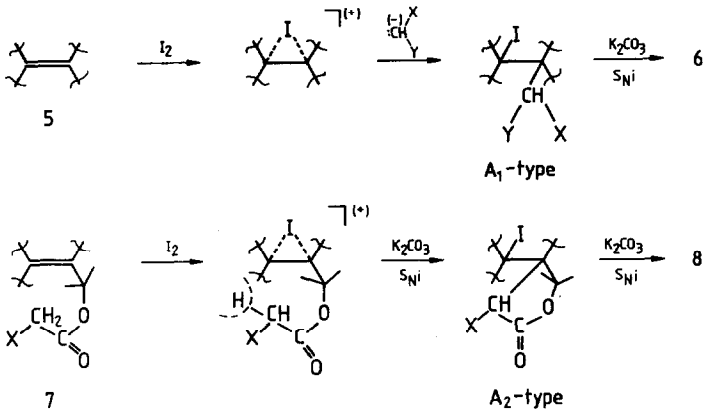


Fig. 5

According to this scheme, iodine reacts first with the olefinic bond to give a π-adduct which is subsequently attacked by the anion from the malonic ester moiety. The mixed adduct (A_1- or A_2-type) so formed will be transformed by an S_Ni process to produce **6** or **8**, respectively.

Careful examination of the ring formation reaction (**7b** to **8b**) in an NMR tube showed, however, that initial attack of iodine at the olefinic double bond can be ruled out and that substitution of one of the acidic hydrogens in the malonic ester moiety proceeds first, and, similar to the reaction of **1a** to **3** and **4** via **2a**, iodomalonic ester derivative **2b** is formed as a stable intermediate. The iodination reaction is quite fast; in five minutes at 80°C in hexadeuteriobenzene solution, the colour of the iodine disappears and the derivative **2b** is formed, together with a few percent of the end product **8b**. The compound **2b** is stable enough to be separated and purified if the K_2CO_3-$KHCO_3$ mixture is removed by filtration, as in the absence of K_2CO_3 the reaction to give **8b** is completely blocked. All manipulations should be carried out in an inert atmosphere and in the dark to protect the iodomalonic acid derivative from easy oxidation by air.

By adding K_2CO_3 and TCMC to the benzene solution of **2b**, the reaction to give **8b** starts again and, even at room temperature, the tranformation is completed in 10-20 minutes depending on the rate of stirring.

For the transformation of the stable iodomalonic ester derivative **2b** to **8b** several routes can be imagined. One of them is the combination of an atom transfer process[8] with an S_Ni reaction (Fig. 6). This can be ruled out, however, because there is no sign of any atom transfer, with the formation of A_2 type product when **2b** is heated in benzene solution for 30 minutes in the absence of K_2CO_3. A certain amount of A_2 can be sup-

posed to be formed but with a much smaller rate than that of the formation of **8b** in the presence of K_2CO_3 and TCMC if hexabutyl-distannane (one of the best catalysts for radical-type fission of the C-I bond[8]) is

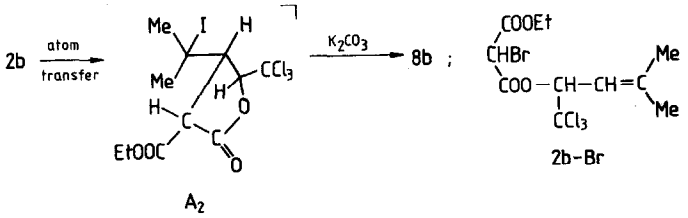


Fig. 6

added to the solution and heating is continued for another 30 minutes. The product has not been separated but its possible formation was indicated by transformation to **8b** by the action of K_2CO_3.

For comparison purposes, the bromo analogue of **2b (2b-Br)** has also been made from **7b** by reaction with bromine and has been characterized (Fig. 6).

2b-Br shows no change during one hour in hot benzene or toluene solution either in the absence or in the presence of solid K_2CO_3 and TCMC, although radical type additions of bromomalonic esters[3] or other bromocarbonyl compounds[15] to the double bond are known.

ESR spectra of the reaction mixture of **2b** with K_2CO_3 and TCMC, in the presence of spin traps phenyl-t-butylnitrone, 2,6-dichloro-nitrosobenzene, and nitric oxide gas[15] have also been taken. In all cases nitroxide radicals have been detected, showing the presence of one or two different radicals. For phenyl-t-butylnitrone a superimposed six-line pattern appears with parameters I: g=2.0058, a_N=15.0 G and a_H= 4.5 G; II: g=2.0059, a_N=13.9 G and a_H=3.5 G. For 2,6-dichloro-nitrosobenzene a triplet can be seen (g= 2.0064, a_N=13.2 G), while in the nitric oxide experiment a superposition of two triplet spectra appears with parameters I: g= 2.0059, a_N =13.8 G and II: g=2.0061, a_N=15.6 G. The application of these spin traps reveals the formation of alkyl radicals in which the unpaired electron is centered on a tertiary carbon atom since all the hyperfine splittings can be accounted for only by the spin trapping moiety.

In harmony with the radical character of cyclopropane ring formation, in the transformation of **7e** or **7f** the stereochemical integrity of the olefinic bonds is lost.

Taking all these facts into account one can, in principle, imagine that the reaction follows a "triplet carbene route" (Fig. 7).

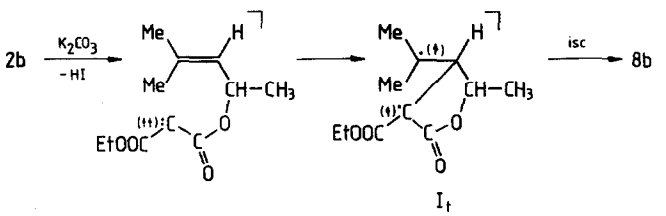


Fig. 7

The anion formed from **2b**, by the action of K_2CO_3, loses iodide anion to give a triplet carbene which results in the formation of another molecule in the triplet state and then the product **8b**, after intersystem crossing. In Fig. 8 we arbitrarily suppose[7] that a triplet carbene is formed in an α-elimination reaction from **2b**.

According to this theory the appearance of the two triplets in the ESR spectrum in the presence of 2,6-dichloro-nitrosobenzene or NO gas may be explained by supposing a reaction of the triplet intermediate I_t at its tertiary radical site with the spin traps giving two diastereomeric nitroxide radicals.

Formation of a carbene by α-elimination in the malonic ester series has not been described in the literature and its existence here has also been strongly questioned by trapping experiments and other experimental data.

Tertiary nitrogen in amines is known to trap carbenes in the form of an ylid[16] which then can enter into 1,3-dipolar cycloaddition reaction with dipolarophiles, e.g. isoquinoline gives a stable ylid in good yield with methoxycarbonylmethylene carbene generated from diazoacetic ester.[17]

In our trapping experiments dimethoxydihydroisoquinoline was added with vigorous stirring and heating to the mixture of **2b** with K_2CO_3 and TCMC in toluene. A pale yellow solid which remained after the work-up procedure consisted of a number of compounds (in the NMR spectrum there were at least 12 methoxy lines) which were not separable from each other by the usual chromatographic techniques. The mass spectrum showed the molecular weight of the ylid **9**, and also its cycloadduct **10**, obtained from the reaction of **9** with diethyl acetylenedicarboxylate (Fig. 8) but, because of the diversity of the trapping reactions, these results are not really characteristic for carbene trapping.[16,17] The formation of a small amount of **9** may be due to the alkylation of the imine nitrogen of the isoquinoline derivative by **2b** and the subsequent deprotonation of the onium salt by K_2CO_3.

Decisive evidence against carbene formation and for the formation of radicals in the reaction of **2b** to give **8b** was obtained in preparative experiments. Thus, it was found that only solid K_2CO_3 is effective in the reaction and that solid potassium t-butoxide, sodium methylate in solid form or dissolved in methanol or in

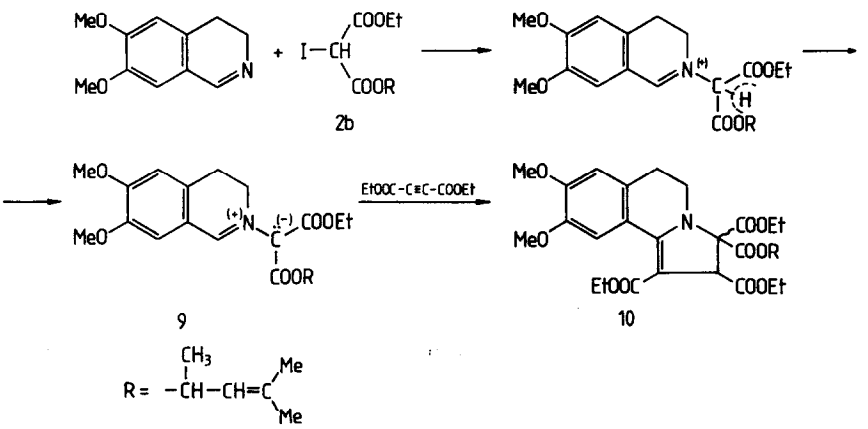


Fig. 8

toluene, potassium t-butoxide in DMSO, diazabicycloundecane, pyridine, and solid potassium hydroxide failed, although all these bases are able to remove the proton from the iodomalonic ester moiety in **2b** so that carbene formation by α-elimination could have occurred.

Compound **2b** either remained unchanged or decomposed without the formation of any detectable amount of compound **8b** in the presence of the bases mentioned.

If the lipophilic onium salt is omitted from the reaction mixture the reaction does not even start, thus showing the importance of the transfer of the anion of **2b** from the K_2CO_3 surface into the reaction mixture.

The results can be summarized and explained by supposing an electron transfer from the anion of **2b** formed on the surface of the solid K_2CO_3 to the molecule **2b** to give a radical anion $R^{(\cdot-)}$, dissociation of which furnishes iodide anion and the radical $R_1^{(\cdot)}$. The transformation of $R_1^{(\cdot)}$ into $R_2^{(\cdot)}$ by an intramolecular radical addition (A_di) and the subsequent reaction of $R_2^{(\cdot)}$ radical so formed with another molecule of **2b** may constitute the chain propagation steps resulting in the formation of a new $R_1^{(\cdot)}$ radical and a neutral intermediate A_2. The sequence of the elemental steps will be completed and the cyclopropane ring is obtained by a proton loss from A_2 followed by an S_Ni reaction (Fig. 9).

It may be supposed that the same mechanism operates for the transformation of other CH-acids into cyclopropane derivatives **6** and **8**, under the experimental conditions described above.

The crucial role of the solid, dry K_2CO_3 and the lipophilic quaternary salt has not been described in the literature, although a SET-induced radical-type fission under PTC conditions was already recognized.[18] It has also been known for a long time that the malonic ester anion can serve as electron source in SET reactions.[19]

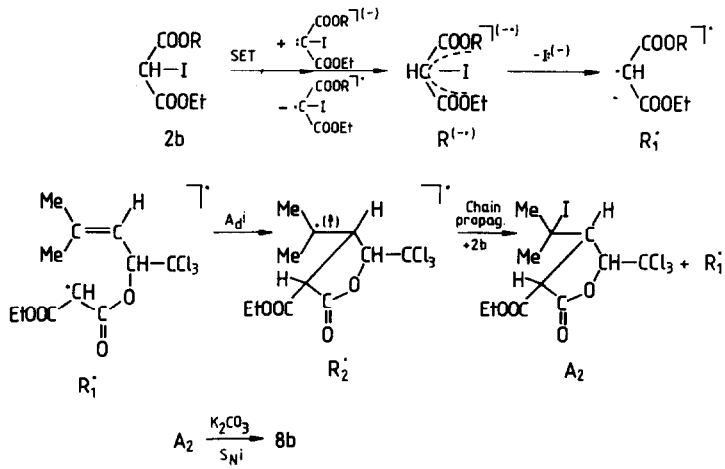


Fig. 9

In the light of the above mechanism the unique role of the solid K_2CO_3 surface can also be explained: it produces always a tiny amount of anion necessary to induce the SET reaction. In case of the presence of too big anion concentration obtained by strong bases in homogeneous solution, the lack of neutral iodomalonic ester would retard the whole chain process.

Experimental

IR spectra were recorded on a SPECORD 75 instrument. ^1H and ^{13}C NMR spectra were recorded on Bruker AM-400 and JEOL FX-100 spectrometers. Chemical shifts are given on the δ scale, δ(TMS)=0 ppm in $CDCl_3$ unless otherwise stated. ESR spectra were recorded on a JEOL JES-FE/3X instrument with 100 kHz field modulation. All spectra were taken at 95 °C in oxygen-free toluene solutions in the magnetic field range of 3180 to 3280 G with the modulation width of 2 G. The g factor was determined by the two center lines of Mn hyperfine pattern of the Mg(Mn)O internal standard. Ms spectra were recorded on VG Trio-2, 70 eV, 200°C and JEOL JMS-01SG-2 instruments. TLC-s were developed on Merck Kieselgel 60 F_{254} plates with an eluent hexane-acetone (4:1). Column chromatography was carried out on Merck Kieselgel 60 to 200 mesh, with the same eluent.

Reaction of CH-acids with olefins (General procedure)

The mixture of **1** (15 mmol), K_2CO_3 (3.3 g, 24 mmol), iodine (3 g, 12 mmol) and TCMC (0.1 g, 0.2 mmol) in 10 cm^3 toluene or THF was refluxed with stirring while **5** (10 mmol) was added in portions for 2 hours. The reaction mixtures in THF were evaporated and taken up in toluene prior to the filtration. The toluene solution was cooled and filtered, the solid was washed with toluene, and the toluene solution washed with 10% $Na_2S_2O_3$ solution, dried over Na_2SO_4 and evaporated. The product was separated by the combination of distillation or crystallization with chromatography.

1,1-Dicyano-2,2-dimethyl-3-(2,2-dimethylvinyl)cyclopropane,[20] **6a** (THF, 18%, purified by chromatography): m.p.:70-74°C, IR (KBr): 2220 cm^{-1}, ^1H-NMR (100 MHz): 4.94(d, J=8 Hz, 1H), 2.44(d, J=8 Hz, 1H), 1.9(s, 6H), 1.44, 1.35(s, s, 6H). Anal. calcd. for $C_{11}H_{14}N_2$: C 75.82, H 8.1, N 16.08; found C 75.66, H 7.94, N 15.92 %

Diethyl 2,2-dimethyl-3-(2,2-dichlorovinyl)cyclopropane-1,1-dicarboxylate,[21,22] **6b** (toluene, 52%): bp:190°C(bath temp.)/0.1 Torr, Ms m/z(%): 308(M^+,8), 273(18), 263(12), 235 (14), 171(22), ^1H-NMR: (100 MHz): 5.72(d, J=8 Hz, 1H), 2.60(d, J=8Hz, 1H), 1.53, 1.41(s, s, 6H). Anal. calcd. for $C_{13}H_{18}Cl_2O_4$: C 50.50, H 5.87; found C 50.41, H 5.94 %

1,1-Dicyano-2,2-dimethyl-3-(2,2-dichlorovinyl)cyclopropane, **6c** (THF, 55%, chromatography): m.p.:104-106°C, IR (KBr): 2230 cm^{-1}, Ms m/z(%): 214(M^+, 34), 199(53), 187(3), 152(55), ^1H-NMR: (100 MHz): 5.72(d, J=8 Hz, 1H), 2.60(d, J=8 Hz, 1H), 1.53, 1.41 (s, s, 6H). Anal. calcd. for $C_9H_8Cl_2N_2$: C 50.26, H 3.75, N 13.02; found C 49.95, H 3.64, N 12.94 %

1,1-Dicyano-2-phenylcyclopropane, **6d** (toluene, 47%, chromatography): IR(neat): 2240 cm^{-1}, ^1H-NMR: (100 MHz): 7.28(m, 5H), 3.15(t, 1H), 2.1(d, 2H), Ms(EI) m/z: 168(M^+), 142, 141, 140. Anal. calcd. for $C_{11}H_8N_2$: C 78.55, H 4.79, N 16.65; found C 78.43, H 4.63, N 16.58 %

1,1-Dicyano-2-methyl-2-phenylcyclopropane,[23,24] **6e** (THF, 6.2%, chromatography): IR(neat): 2240 cm^{-1}, ^1H-NMR (100 MHz): 7.40(s, 5H), 2.35(d, 1H), 1.95(d, 1H), 1.78(s, 3H). Anal. calcd. for $C_{12}H_{10}N_2$: C 79.1, H 5.53, N 15.37; found C 78.95, H 5.56, N 15.21 %

Diethyl 2-butylcyclopropane-1,1-dicarboxylate, **6f** (toluene, 38%, chromatography) IR(neat): 1725 cm^{-1}, ^1H-NMR(100 MHz): 0.88 (t, 3H, J=6 Hz), 1.25-1.38(m, 8H), 4.28 (qq, 4H), Ms m/z(%): 242 (M^+, 10), 200(11.5), 197(40.5), 173 (44.7), 160(87.6), 127(100). Anal. calcd. for $C_{13}H_{22}O_4$: C 64.44, H 9.15; found C 64.18, H 9.06 %

Preparation of diethyl iodomalonate, formation of ethyl ethanetetracarboxylate[11] (3) and ethyl ethylenetetracarboxylate[11] (4)

A mixture of diethyl malonate (1.6 g, 10 mmol), iodine (3 g, 12 mmol), potassium carbonate (3 g, 22 mmol) and TCMC in 10 cm^3 toluene was vigorously stirred and refluxed under nitrogen for 2 h. The reaction mixture consisted of *diethyl malonate* (retention time: 9 min 15 sec, Hewlett Packard 58-90, 30 m DB-210 column, from 60 to 200°C with 10°C/min, He as carrier gas), *diethyl iodomalonate* (R_t: 10 min 42 sec, Ms m/z: 286(M^+ ,60%), 241(30), 214 (25), 186(100), 168(45), 159 (20)), *ethyl ethanetetracarboxylate* **3** (R_t: 19 min 33 sec), *ethyl ethylenetetracarboxylate* **4** (R_t: 21 min 58 sec).

For preparation of **3** and **4** the mixture was filtered, the solution was evaporated to dryness and the product crystallized. Yield of **3** and **4**: 70%. For their characterization see ref. 11

Preparation of malonic acids "mixed" esters

1. Malonic acid monoester chlorides

Malonic acid diethyl or dimethyl ester were hydrolysed to the monoester using the method of Breslow et al.[25] 0.1 Mol of the crude acid and several drops of dimethyl formamide were dissolved in 150 cm^3 chloroform and 8 cm^3 (13.1 g, 0.11 mol) thionylchloride was added dropwise into the solution. The mixture was refluxed till no more gas evolved then the solvent and the excess of the thionylchloride was evaporated, the residue fractionated in vacuo.

Malonic acid chloride monoethyl ester: b.p.: 70°C/16 Torr (70%, lit b.p.: 63-64°C/10 Torr[26]).

Malonic acid chloride monomethyl ester: b.p.: 64°C/15 Torr (65%, lit. b.p.: 57-59°C/12 Torr[26]).

2. Malonic acid "mixed" esters

20 Mmol of acid chloride and 20 mmol of the appropriate alcohol were dissolved in 50 cm^3 hexane and 1.5 cm^3 (23 mmol) triethylamine was added dropwise into the solution. The mixture was refluxed for 6 h then the hexane was evaporated the residue was diluted with chloroform and water, the layers were separated, the organic washed with diluted HCl and with water, dried over $MgSO_4$. After evaporation of the solvent, the residue was distilled in vacuo. In some cases the crude ester obtained was pure enough for the cyclization step without distillation.

Methyl (4-methyl-1,1,1-trichloro-pent-3-ene)-2-yl malonate, **7a**: 70%, IR(neat): 1730 cm^{-1}, ^{1}H-NMR (100 MHz, C_6D_6): 2.18(s, 3H), ^{13}C-NMR(100 MHz, C_6D_6): 53.1. Anal. calcd. for $C_{10}H_{13}Cl_3O_4$: C 39.56, H 4.32; found C 39.21, H 4.18 %

Ethyl (4-methyl-1,1,1-trichloro-pent-3-ene)-2-yl malonate, **7b**: 70%, b.p. 106-110°C/0.1 Torr, IR(neat): 1740 cm^{-1}, ^{1}H-NMR(100 MHz): 1.29(t, 3H), 1.83(d, 1H, J=1.2 Hz), 1.86(d, 1H, J=1.2 Hz), 3.47(s, 2H), 4.21(q, 2H), 5.32 (dq, 1H, J_d= 9.3 Hz, J_q=1.2 Hz), 6.05(d, 1H, J=9.3 Hz), ^{13}C-NMR(100 MHz): 13.9, 19.1, 26.0, 41.3, 61.5, 79.2, 99.4, 116.4, 120.1, 164.6, 165.5. Anal. calcd. for $C_{11}H_{15}Cl_3O_4$: C 41.6, H 4.76; found C 41.35, H 4.53 %

Ethyl allyl malonate, **7c**: 60%(crude product), IR(neat): 1745, 1735 cm^{-1}, ^{1}H-NMR 100 MHz): 1.3(m, 3H), 3.34(s, 2H), 4.25 (qq, 4H), 4.3(s, 1H), 4.8(s, 2H).

Ethyl Z-crotyl malonate, **7e**: 75%, IR(neat): 1725 cm^{-1}, ^{1}H-NMR(100 MHz): 1.27(t, 3H), 1.70(dm, 3H), 4.19(q, 2H), 4.70(d, 2H), 5.55(dm, 1H), 5.74(dm, 1H, J=11.1 Hz), ^{13}C-NMR(100 MHz): 12.4, 13.5, 40.9, 60.3, 60.8, 123.3, 129.4, 165.9. Anal. calcd. for $C_9H_{14}O_4$: C 58.05, H 7.58; found C 57.83, H 7.61 %

Ethyl E-crotyl malonate, **7f**: 75%, IR (neat): 1730 cm^{-1}, ^{1}H-NMR(100 MHz): 1.26(t, 3H), 1.71(dm, 3H), 4.18(q, 2H), 4.55 d, 2H), 5.38(dm, 1H, J=15.1 Hz), 5.80(dm, 2H), ^{13}C-NMR: 13.4, 17.0, 40.9, 60.7, 65.3, 124.2, 131.0. Anal. calcd. for $C_9H_{14}O_4$: C 58.05, H 7.58; found C 58.12, H 7.49 %

Ethyl (1,1-dimethyl-prop-2-ene)-1-yl malonate, **7g**: 55% (crude product), IR(neat): 1720 cm^{-1}

Reaction of the diketene-acetone adduct with 1,1,1-trichloro-4-methyl-pent-3-ene-2-ol[2a]

1,1,1-Trichloro-4-methyl-pent-3-ene-2-yl acetoacetate, **7d** was prepared according the method of Carroll and Balder.[27] 1.42 g (10 mmol) of 2,2,6-trimethyl-1,3-dioxen-4-one, 2.1 g (10 mmol) of 1,1,1-trichloro-4-methyl-pent-3-ene-2-ol and a catalytic amount of p-toluenesulphonic acid were refluxed in toluene for 6 h. The cooled solution was washed with water, dried over $MgSO_4$, the solvent was evaporated. Yield: 70%, b.p.: 82-90°C/0.1 Torr, IR (neat): 1760, 1710 cm^{-1}, ^{1}H-NMR (100 MHz): 1.9(s, 6H), 2.31(s, 3H), 3.56(s, 2H), 5.34(d, 1H, J=8 Hz), 6.09(d, 1H, J=8 Hz), 11.7(enol H). Anal. calcd. for $C_{10}H_{13}Cl_3O_3$: C 41.76, H 4.56; found C 41.25, H 4.34 %

1,1,1-Trichloro-4-methyl-pent-3-ene-2-yl cyanoacetate, **7h**

1.7 g (20 mmol) Of cyanoacetic acid, 4 g (20 mmol) of 1,1,1-trichloro-4-methyl-pent-3-en-2-ol and a catalytic amount of p-toluenesulphonic acid in 50 cm^3 toluene was refluxed with continuous removing of the water formed. The mixture was washed with water, dried, the solvent was evaporated. Yield: 60% (crude product), IR(neat): 2210, 1730 cm^{-1}

Ethyl 1,1,1-trichloro-4-methyl-3-pentene-2-yl-iodomalonate, **2b**

The mixture of 3.3 g (24 mmol) K_2CO_3, 3 g (12 mmol) iodine, 0.1 g (0.2 mmol) TCMC and 3.4 g (12 mmol) **7b** in 20 cm^3 toluene was stirred at 110°C till the colour of the iodine disappeared (approx. 5 min.). Then the solid was removed the solution washed with $Na_2S_2O_3$ solution and with water, dried and evaporated, the residue was purified by column chromatography. ^{1}H-NMR(100 MHz): 1.5, 1.7, 5.5, 6.28 (d), 6.35(d), 2:1 ratio, no sign at 3.3 ppm; ^{13}C-NMR(100 MHz): 15.5, 26.3, 63.6, 64.0 (2:1) 80.3, 81.3, 81.4, 92.09, 116.5, 116.7, 146.4.

Ethyl 1,1,1-trichloro-4-methyl-3-pentene-2-yl-bromomalonate, **2b-Br**

To a solution of 1 g **7b** (3.1 mmol) and one drop of HBr in 20 cm^3 carbon tetrachloride 0.16 cm^3 (0.49 g, 3.1 mmol) bromine was added dropwise at room temperature. After the addition the stirring was continued for another 1 h at room temperature and 2 h at 60°C. The cooled solution was washed with $Na_2S_2O_3$ solution and with water, dried and evaporated to give the pure product with quantitative yield. ^{1}H-NMR(100 MHz): 1.30 (t, 3H), 1.84 (d, 3H, J=1.2 Hz), 1.88 (d, 3H, J= 1.2Hz), 4.30 (q), 4.31(q, 2H), 4.93 (s), 4.95 (s, 1H); ^{13}C-NMR(100 MHz): 13.9, 19.2, 26.1, 41.9, 42.1, 63.3, 80.7, 98.9, 115.7, 145.8, 162.6, 162.7, 163.7. Anal. calcd. for $C_{11}H_{14}BrCl_3O_4$: C 33.32, H 3.56; found C 33.06, H 3.51 %

Cyclization of the esters (General procedure)

To a mixture of 3.3 g (24 mmol) K_2CO_3, 3 g (12 mmol) iodine, 0.1 g (0.2 mmol) TCMC and 20 cm^3 toluene, 10 mmol of the ester **7a-h** in 5 cm^3 toluene was added dropwise for 1 h at 110°C with vigorous stirring. After a further 30 min heating the mixture was cooled, the solid was filtered off, the filtrate was washed

with 10% $Na_2S_2O_3$ solution and with water, dried over $MgSO_4$, the solvent was evaporated, the residue purified.

6,6-Dimethyl-4-trichloromethyl-3-oxa-bicyclo[3,1,0]hexane-2-one-1-carboxylic acid methyl ester, **8a**, 90%, m.p.: 114-116°C, b.p.:110-115°C/0.1 Torr, IR(KBr): 1780, 1730 cm^{-1}, ^1H and ^{13}C-NMR see Table 1, Ms m/z(%): 300(M^+, 18). Anal. calcd. for $C_{10}H_{11}Cl_3O_4$: C 39.83, H 3.68; found C 39.64, H 3.59 %

6,6-Dimethyl-4-trichloromethyl-3-oxa-bicyclo[3,1,0]hexane-2-one-1-carboxylic acid ethyl ester, **8b**, 90%, b.p.: 115-117°C/0.1 Torr (lit. 123-125°C/0.3 Torr[28]), m.p.: 75°C, IR(KBr): 1780, 1730 cm^{-1}, ^1H-NMR (100 MHz): 4.57(s, 2H), 4.28 (qua, 2H, J=6 Hz), 2.81 (s, 2H), 1.38(s, 6H), Ms m/z (%): 318(M^++4, 14.1), 316(M^++2, 38.8), 314(M^+, 26.1), 277(22), 275 (54.1), 273(80), 271(15.5), 269(15.5), 247(20.0), 245 (25.5), 243(5.5), 241 (5.5), 231(5.5), 229(21.4), 227(22.9), 223(9.7), 221(12.6), 197(17.0), 151 (100). Anal. calcd. for $C_{11}H_{13}Cl_3O_4$: C 41.87, H 4.15; found C 41.67, H 4.06 %

3-Oxa-bicyclo[3,1,0]hexane-2-one-1-carboxylic acid ethyl ester, **8c**, 60%(chromatography), IR(neat): 1780, 1720 cm^{-1}, ^1H-NMR(100 MHz): 1.3 (m, 2H), 2.05(m, 2H), 2.74(m, 1H), 4.23 (m, 4H). Anal. calcd. for $C_8H_{10}O_4$: C 56.47, H 5.92; found C 56.48, H 5.84%

1-Acetyl-6,6-dimethyl-4-trichloromethyl-3-oxa-bicyclo[3,1,0]-hexane-2-one, **8d**, 55% (chromatography), IR(KBr): 1790, 1720 cm^{-1}, ^1H-NMR(100 MHz): 1.81(m, 6H), 1.98(s, 3H), 2.51 (s, 1H), 5.03(s, 1H). Anal. calcd. for $C_{10}H_{11}Cl_3O_3$: C 42.06, H 3.88; found C 41.95, H 3.84 %

Exo- and endo-6-methyl-3-oxa-bicyclo[3,1,0]hexane-2-one-1-carboxylic acid ethyl ester, **8e** and **8f**, 80% (see Discussion), IR(neat): 1780, 1730 cm^{-1}, ^1H- and ^{13}C-NMR see Table 1.

4,4-Dimethyl-3-oxa-bicyclo[3,1,0]hexane-2-one-1-carboxylic acid ethyl ester, **8g**, 65%, m.p.: 80-80.5°C(hexane), IR(KBr): 1780, 1730 cm^{-1}, ^1H-NMR(100 MHz): 1.15-1.60(m, 9H), 1.8(dd, 2H), 2.48(dd, 1H), 4.23(q, 2H), Ms m/z(%): 198(M^+, 7.1), 183(100), 155(12.5), 153(8.4), 111(7.2), 81 (17.5), 43(56.8). Anal. calcd. for $C_{10}H_{14}O_4$: C 60.59, H 7.12; found C 60.51, H 7.02 %

6,6-Dimethyl-4-trichloromethyl-3-oxa-bicyclo[3,1,0]hexane-2-one-1-carbonitrile, **8h**, 70%, m.p.: 146-148°C (hexane), IR (KBr): 2220, 1760 cm^{-1}, ^1H-NMR(100 MHz): 1.49 (d, 6H, J=8Hz), 2.92(s, 1H), 4.62(s, 1H). Anal. calcd. for $C_9H_8Cl_3NO_2$: C 40.26, H 3.00, N 5.22; found C 40.13, H 2.93, N 5.16 %

Trapping experiments

a. Formation of the ylid from **2b**

To a suspension of 0.2 g K_2CO_3, 0.2 g iodine and one drop TCMC in 10 cm^3 toluene 0.2 g **7b** was added at 100°C and the mixture was stirred till the disappearance of the color of the iodine (appr. 5 min). Then 0.2 g of dimethoxydihydroisoquinoline was added to this mixture with stirring and heating continued for another 60 min. Then the mixture was washed with $Na_2S_2O_3$ solution and with water, dried and evaporated, the residue purified by chromatography. The product is a yellow foam, m.p.: 55-59°C, Ms(CI): 506(M^++H) .

b. Formation of the cycloadduct

To the solution of the ylid prepared as above 0.2 cm^3 diethyl acetylenedicarboxylate was added and the mixture was further stirred for 1 h. The work-up and chromatography resulted a yellow oil. Ms: 675(M^+) .

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