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Oxidation of 2-Substituted Cycloalkanones with Cerium(IV) Sulfate Tetrahydrate in Alcohols and Acetic Acid

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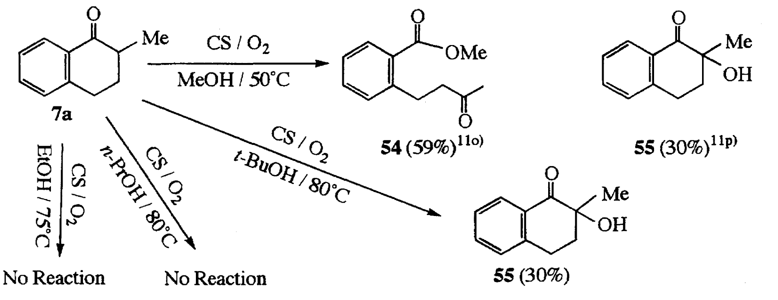
The reaction of 2-substituted cycloalkanones with cerium(IV) sulfate tetrahydrate (CS) in alcohols and acetic acid gave the corresponding alkyl esters of oxo acids (80—96%) and oxo acids (78—96%), respectively, by oxidative cleavage of the C(R)–C=O bond. In the case of 2-iodocycloalkanones in methanol, the dimethyl ester was obtained in good yield. A treatment of 5α-cholestan-3-one with CS in methanol produced 2-acetal 3-ester of 2,3-seco derivative in good yield. The effects of cerium(IV) and copper(II) salts are also discussed.

Oxo carboxylic acids and esters are important as intermediates in organic synthesis. There are many syntheses of oxo esters involving a regiospecific oxidative ring opening of cycloalkanones with iron(III) salts and oxygen in various alcohols,[1] ring opening oxygenation upon a treatment with $VO(OEt)Cl_2$ in alcohol under oxygen,[2] an electrochemical oxidation of enol ether of cyclohexanone,[3] a specific cleavage of silyl enol ethers by $MoO_2(acac)_2$ (Hacac = 2,4-pentanedione) and *t*-butyl peroxide,[4] and Mo-catalyzed oxygenation of cyclic ketones by molecular oxygen.[5] It is known that many of these reactions proceed by the Baeyer–Villiger-type process. Atlamsani et al. have recently reported that the oxidation of 2-methylcyclohexanone by oxygen in the presence of heteropolyvanadates in $AcOH–H_2O$ gives 6-oxoheptanoic acid.[6]

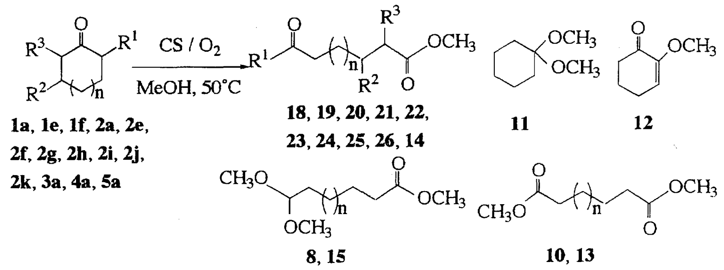
We investigated novel iodination methods of ketones using iodine–copper(II) acetate.[7] These methods, however, have disadvantages due to the fact that the produced iodide ions are consumed as copper(I) iodide. During the course of our studies, some new reactions have been found by using iodine-ammonium cerium(IV) nitrate (CAN).[8] The reaction of 5α-cholestan-3-one with iodine and CAN in acetic acid–water (9 : 1) at 50 °C for 22 h gives the 2,3-seco-5α-cholestane-2,3-dioic acid,[9] and the reaction of 2-alkylcycloalkanone with iodine–cerium(IV) salts in alcohols (methanol, ethanol, 1-propanol, and 2-propanol) yields the corresponding oxo ester.[10] Through our studies, it was found that iodine–CAN and iodine–cerium(IV) sulfate tetrahydrate (CS) are useful reagents for the synthesis of a large number of iodo compounds. Here, we report that the reaction of cycloalkanone, 2-alkylcycloalkanone, and 2-halocycloalkanone with CS in alcohols and acetic acid yields the corresponding esters of oxo acids, diesters, oxo acids, and dioic acids.

Results and Discussion

The reaction of 2-alkylcycloalkanones with CS in methanol under an oxygen atmosphere gave the corresponding methyl ester of oxo acid in good yields. The results are summarized in Table 1. On the basis of these results, it was found that an oxidative cleavage of the C–C bond occurred at the C^1 and C^2 position, i.e. the C(R)–C=O bond, and that the reaction of 2-methyl- (**1e**) or 2-ethylcyclopentanone (**1f**) proceeded faster than 2-alkylcyclohexanone due to the unstable envelope conformation of its five-membered ring. It is particular noteworthy that by a comparision with the reported results,[10] this reaction may provide a new method for the synthesis of alkyl ester of oxo acid. A difference in reactivity was observed in the oxidation of unsubstituted cycloalkanones, such as cyclopentanone (**1a**), cyclohexanone (**2a**), cycloheptanone (**3a**), cyclooctanone (**4a**), cyclododecanone (**5a**), and camphor (**6**), by comparisions with 2-alkylcycloalkanones. It was found that in the case of unsubstituted cy-



Scheme 1.



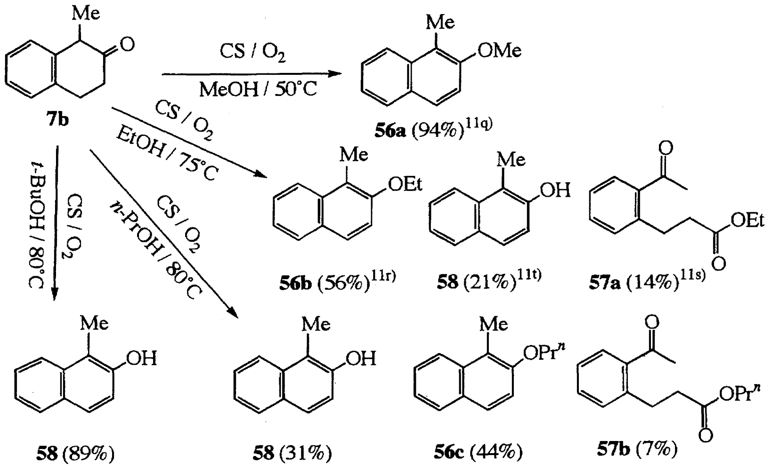
1e, 18: R^1=Me, R^2=R^3=H, n=0
1f, 19: R^1=Et, R^2=R^3=H, n=0
2e, 20: R^1=Me, R^2=R^3=H, n=1
2f, 21: R^1=Et, R^2=R^3=H, n=1
2g, 22: R^1=R^2=Me, R^3=H, n=1
2h, 23: R^1=R^3=Me, R^2=H, n=1
2i, 24: R^1=Pr^n, R^2=R^3=H, n=1
2j, 25: R^1=Pr^i, R^2=Me, R^3=H, n=1
2k, 26: R^1=Ph, R^2=R^3=H, n=1

1a: R^1=R^2=R^3=H, n=0
2a: R^1=R^2=R^3=H, n=1
3a: R^1=R^2=R^3=H, n=2
4a: R^1=R^2=R^3=H, n=3
5a: R^1=R^2=R^3=H, n=7
8: n=0; **10**: n=1; **13**: n=2
14: R^1=R^2=R^3=H, n=2
15: n=3.

Table 1. Oxidative Cleavage Reactions of 2-Alkylcycloalkanones with CS[a)]

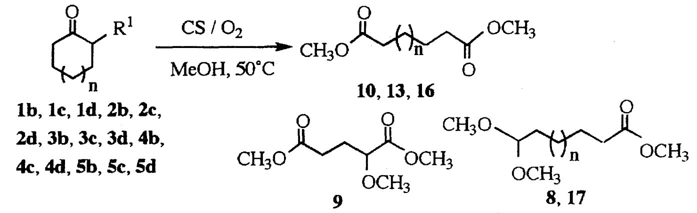
Run	Substrate	mol equiv of CS	Time (h)	Product (%)[b)]
1	**1e**	2.5	2	**18** (92)[10]
2	**1f**	2.5	2	**19** (88)[11j]
3	**2e**	2.5	6	**20** (92)[10]
4	**2f**	2.5	8	**21** (83)[11k]
5	**2g**	2.5	6	**22** (85)[10]
6	**2h**	2.5	6	**23** (87)[11l]
7	**2i**	2.5	10	**24** (96)[10]
8	**2j**	2.5	12	**25** (80)[10]
9	**2k**	2.5	10	**26** (85)[10]
10	**1a**	5	8	**8** (46)[11a]
11	**2a**	5	8	**10** (35)[11c] + **11** (38)[11d] + **12** (7)[11e]
12	**3a**	5	5	**13** (49)[11f] + **14** (19)[11g]
13	**4a**	5	5	**15** (51)[11h]
14	**5a**	5	5	No reaction
15	**6** (Camphor)	2.5	6	No reaction

a) Reaction conditions: substrate (2.0 mmol), CS (5.0 mmol), and MeOH (20 ml) were employed. b) Isolated yield and the number at upper-right of a compound is No. of reference.



Scheme 2.

cloalkanone, the yield was poor.[2,6b] Thus, in order to obtain the diester, we attempted the reaction of 2-halocycloalkanone with CS in methanol under an oxygen atmosphere. These results are summarized in Table 2, and seem to indicate that this reaction provides a new simple method for preparing the diester. From these results, it was found that the reaction of

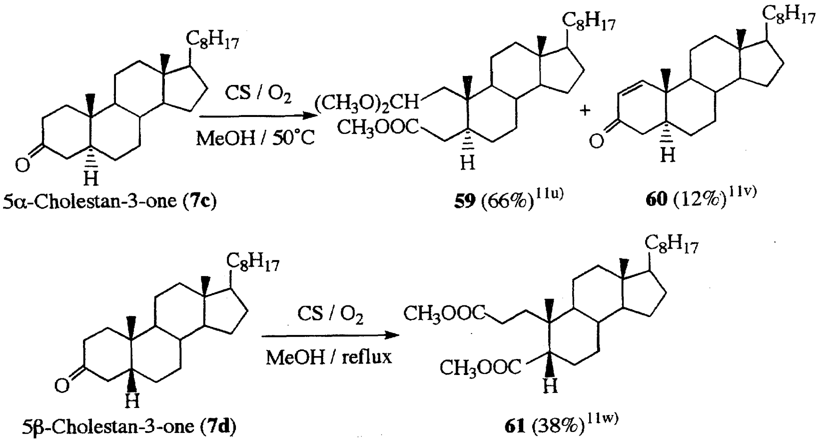


1b: R^1=Cl, n=0
1c: R^1=Br, n=0
1d: R^1=I, n=0
2b: R^1=Cl, n=1
2c: R^1=Br, n=1
2d: R^1=I, n=1
3b: R^1=Cl, n=2
3c: R^1=Br, n=2
3d: R^1=I, n=2
4b: R^1=Cl, n=3
4c: R^1=Br, n=3
4d: R^1=I, n=3
5b: R^1=Cl, n=7
5c: R^1=Br, n=7
5d: R^1=I, n=7
8: n=0; **10**: n=1
13: n=2
16: n=3; **17**: n=7

Table 2. Oxidative Cleavage Reactions of 2-Halocycloalkanones with CS in MeOH[a)]

Run	Substrate	Time (h)	Product (%)[b)]
1	**1b**	8	**8** (65)
2	**2b**	10	**10** (76)
3	**3b**	10	**13** (42)
4	**4b**	10	**16** (12)
5	**5b**	10	No reaction
6	**1c**	2	**8** (42)
7	**2c**	6	**10** (64)
8	**3c**	2	**13** (78)
9	**4c**	2	**16** (11) [11c]
10	**5c**	5	No reaction
11	**1d**	8	**8** (53) + **9** (23) [11b]
12	**2d**	8	**10** (63)
13	**3d**	8	**13** (63)
14	**4d**	6	**16** (95)
15	**5d**	6	**17** (58) [11i]

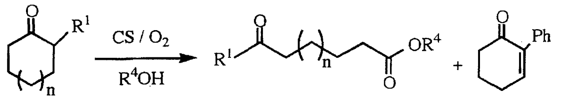
a) Reaction conditions: substrate (2.0 mmol), CS (5.0 mmol), and MeOH (20 ml) were employed.
b) Isolated yield and the number at upper-right of a compound is No. of reference.



Scheme 3.

2-iodocyclohexanone (**2d**), 2-iodocycloheptanone (**3d**), and 2-iodocyclooctanone (**4d**) yielded the corresponding diester in good yield, compared with that of the chloro or bromo derivatives. It is considered that the difference in the reactivity of iodo compounds is due to the unstable properties[10] compared with that of chloro or bromo ketones. In the case of 2-halocyclopentanone and 2-iodocyclododecanone, the ω,ω-dialkoxy ester was obtained, not the diester. It is considered that the oxidative cleavage of the C(X)–C=O bond gave the ω-formyl ester, followed by acetalization.

In order to investigate the effect of other alcohols (ethanol, 1-propanol, 2-propanol, and 2-methyl-2-propanol), the reaction of **2e** with CS in ethanol at 75 °C for 18 h gave the oxo ester (**28**) in 57% yield. The results are summarized in Table 3. From these results, it was found that in alcohols the rate ratio of the oxidative cleavage reaction was in the following order: MeOH > EtOH > n-PrOH > i-PrOH > t-BuOH. It is seemed that in the case of a bulkier alkoxy



1e, **2e**, **2f**, **2i**, **2k**

27, **28**, **29**, **30**, **31**, **32**, **33**, **34**, **35**, **36**, **37**, **38**, **39**, **40**, **41**

42

27: R^1=Me, R^4=Et, n=0
28: R^1=Me, R^4=Et, n=1
29: R^1=R^4=Et, n=1
30: R^1=Pr^n, R^4=Et, n=1
31: R^1=Ph, R^4=Et, n=1
32: R^1=Me, R^4=Pr^n, n=0
33: R^1=Me, R^4=Pr^n, n=1
34: R^1=Et, R^4=Pr^n, n=1
35: R^1=R^4=Pr^n, n=1
36: R^1=Ph, R^4=Pr^n, n=1
37: R^1=Me, R^4=Pr^i, n=0
38: R^1=Me, R^4=Pr^i, n=1
39: R^1=Pr^n, R^4=Pr^i, n=1
40: R^1=Ph, R^4=Pr^i, n=1
41: R^1=Me, R^4=Bu^t, n=1

Table 3. Oxidative Cleavage Reactions of 2-Alkylcycloalkanones with CS in Alcohols[a)]

Run	Substrate	Solvent (R^4)	Time (°C)	Time (h)	Conversion (%)	Yield (%)[b)]
1	**1e**	EtOH	75	12	71	**27** (57)[10]
2	**1e**	*n*-PrOH	80	12	51	**32** (45)[10]
3	**1e**	*i*-PrOH	80	12	33	**37** (24)
4	**1e**	*t*-BuOH	80	12	0	No reaction
5	**2e**	EtOH	75	18	75	**28** (57)[10]
6	**2e**	*n*-PrOH	80	18	65	**33** (42)[10]
7	**2e**	*i*-PrOH	80	18	25	**38** (10)[10]
8	**2e**	*t*-BuOH	80	18	11	**41** (5)
9	**2f**	EtOH	75	18	73	**29** (48)[10]
10	**2f**	*n*-PrOH	80	18	63	**34** (38)
11	**2i**	EtOH	75	18	38	**30** (30)[11m]
12	**2i**	*n*-PrOH	80	18	32	**35** (24)
13	**2i**	*i*-PrOH	80	18	25	**39** (16)
14	**2i**	*t*-BuOH	80	18	0	No reaction
15	**2k**	EtOH	75	18	80	**31** (68)[10]
16	**2k**	*n*-PrOH	80	18	81	**36** (69)[10]
17	**2k**	*i*-PrOH	80	18	45	**40** (29) + **42** (3)[11n]
18	**2k**	*t*-BuOH	80	18	65	**42** (51)

a) Reaction conditions: substrate (2.0 mmol), CS (5.0 mmol) and alcohol (20 ml) were employed. b) Isolated yield and the number at upper-right of a compound is No. of reference.

group, the yields were diminished compared with those of the methoxy group, and that the reaction of 2-phenylcyclohexanone (**2k**) with CS in 2-methyl-2-propanol at 80 °C for 18 h gave the unsaturated ketone [2-phenyl-2-cyclohexen-1-one (**42**)] in 51% yield.

Therefore, those substrates which are easy to aromatize were employed. The reaction of **7a** with CS in methanol at 50 °C for 6 h gave methyl *o*-(3-oxobutyl)benzoate (**54**) (59%) and 2-methyl-2-hydroxy-3,4-dihydro-1(2*H*)-naphthalenone (**55**) (30%). These results are summarized in Schemes 1 and 2. Although the reaction mechanism has not yet been clarified, it seems that the cerium(IV)-alcohol complex is preferentially formed in the direction of enolization,[9] which is considered to undergo a similar oxygenation reaction as reported.[1,2] From these results, it was found that in alcohols, except for methanol, the oxidative cleavage reaction did not occur. In Scheme 2, aromatized compounds were obtained in alcohols, especially in methanol and 2-methyl-2-propanol.

The reaction of certain 2-alkylcycloalkanones with other cerium(IV) salts and some copper(II) salts gave the oxo esters in poor yield compared with CS. In the case of copper(II) perchlorate, the reaction of **1e** gave methyl 5-oxohexanoate (**18**) in 73% yield. These results are summarized in Table 4.

5*α*-Cholestan-3-one (**7c**) and 5*β*-isomer (**7d**) were also treated with CS in methanol, which is shown in Scheme 3. From the results, it was found that the reaction of **7c** gave methyl 2,2-dimethoxy-2,3-seco-5*α*-cholestan-3-oate (**59**) in good yield, and that the reaction of **7d** gave dimethyl 3,4-seco-5*β*-cholestane-3,4-dioate (**61**) in low yield. These results show that this reaction is applicable to a steroidal ketone and that the cleavage of the C–C bond is in agreement with the direction of enolization in 5*α*- and 5*β*-cholestan-3-one.

On the basis of these results, it was found that the present oxidative cleavage reaction of the C–C bond of 2-alkylcycloalkanone using CS in alcohol proceeds well under conditions that are more effective than those with the method using other cerium(IV) salts and some copper(II) salts.

On the other hand, the oxidation of unsubstituted cycloalkanone or 2-alkylcycloalkanone using CS or copper(II) chloride in acetic acid gave the corresponding dicarboxylic acid or oxo carboxylic acid in good yields. These results are summarized in Table 5. From these results, it seems particularly noteworthy that this reaction may provide a new synthetic method for dicarboxylic acid and oxo carboxylic acid. Moreover, it was concluded that cerium(IV) sulfate and

Table 4. Oxidative Cleavage Reactions of 2-Alkylcycloalkanones with Cerium(IV) and Copper(II) Salts in MeOH at 50 °C[a)]

Run	Substrate	Ce(IV) or Cu(II) Salt (mol equiv)	Time (h)	Product (%)[b)]
1	**2e**	CAN	4	**20** (21)
2	**2e**	CAS	15	**20** (45)
3	**2e**	$Ce(OTf)_4$ (2)	16	**20** (20)
4	**2e**	$Ce(OH)_4$ (1)	15	**20** (0)
5	**2e**	$CeCl_3$ (2)	15	**20** (8)
6	**2e**	$Yb(OTf)_3$ (0.1)	14	**20** (5)
7	**2e**	CuO (2)	12	**20** (0)
8	**2e**	$Cu(ClO_4)_2\cdot 6H_2O$ (2)	10	**20** (50)
9	**1e**	$Cu(ClO_4)_2\cdot 6H_2O$ (1)	18	**18** (73)
10	**2g**	$Cu(ClO_4)_2\cdot 6H_2O$ (1)	24	**22** (28)
11	**2i**	$Cu(ClO_4)_2\cdot 6H_2O$ (1)	24	**24** (28)
12	**1e**	$Ce(OAc)_2$ (1)	21	**18** (0)
13	**1e**	$CuCl_2\cdot 2H_2O$ (2)	28	**18** (70)
14	**2e**	$CuCl_2\cdot 2H_2O$ (0.2)	32	**20** (3)
15	**2e**	$CuCl_2\cdot 2H_2O$ (0.5)	12	**20** (33)
16	**2e**	$CuCl_2\cdot 2H_2O$ (1)	22	**20** (42)
17	**2e**	$CuCl_2\cdot 2H_2O$ (2)	13	**20** (59)
18	**2g**	$CuCl_2\cdot 2H_2O$ (1)	42	**22** (42)
19	**2i**	$CuCl_2\cdot 2H_2O$ (2)	26	**24** (50)
20	**2j**	$CuCl_2\cdot 2H_2O$ (2)	8	**25** (50)
21	**1e**	$CuSO_4\cdot 5H_2O$ (1)	20	**18** (46)
22	**1g**	$CuSO_4\cdot 5H_2O$ (2)	20	**18** (15)
23	**2e**	$CuSO_4\cdot 5H_2O$ (0.5)	20	**20** (22)
24	**2e**	$CuSO_4\cdot 5H_2O$ (1)	20	**20** (22)

a) Reaction conditions: substrate (2.0 mmol) and solvent (20 ml) were employed. b) Isolated yield.

copper(II) chloride are efficient oxidative C–C bond-cleavage agents for cycloalkanone and 2-alkylcycloalkanone.

In conclusion, we encountered a novel cerium(IV) sulfate tetrahydrate mediated oxidative cleavage of 2-substituted cycloalkanones in alcohols and acetic acid, resulting in an efficient and direct synthesis of alkyl ester of oxo acid, diester, oxo acid, and dioic acid. It is noteworthy that the present reaction affords a new synthetic method, that is more convenient than the method used heretofore.

Experimental

IR spectra were measured using a JASCO FT/IR-230 grating infrared spectrometer. NMR spectra were measured using a JEOL GSX 400 Model Spectrometer in deuteriochloroform with TMS as an internal standard. High-resolution mass spectra were recorded at 75 eV on a JEOL JMS-O1SG-2 instrument with a direct inlet.

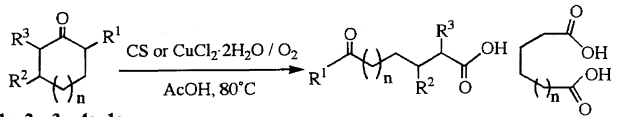
Typical Procedures: Reaction of 2-Methylcyclohexanone with CS in MeOH. A mixture of 2-methylcyclohexanone (**2e**) (0.224 g, 2.00 mmol) and cerium(IV) sulfate tetrahydrate (2.013 g, 5.0 mmol) in MeOH (20 ml) was stirred at 50 °C under an oxygen atmosphere for 6 h. A white precipitate was filtered off and the solvent was removed under reduced pressure. The residue was poured into water (20 ml) and extracted with diethyl ether (2×25 ml). The ethereal solution was washed successively with saturated aq NaCl (10 ml), aq sodium hydrogencarbonate solution (10 ml) and water (10 ml) and dried by Na_2SO_4 and concentrated in a vacuum. The resulting oil was chromatographed on silica gel. Elution with hexane–ether (4 : 1) gave methyl 6-oxoheptanoate (**20**) as a pale-yellow oil (0.290 g, 92%).

Reaction of 2-Methylcyclohexanone with CS in Other Alcohols. A mixture of 2-methylcyclohexanone (**2e**) (0.224 g, 2.00 mmol) and CS (2.013 g, 5.00 mmol) in EtOH (20 ml) was stirred at 75 °C under an oxygen atmosphere for 18 h. After the usual work up, the resulting oil was chromatographed on silica gel. Elution with hexane–ether (4 : 1) gave ethyl 6-oxoheptanoate (**28**) as a pale-yellow oil (0.196 g, 57%).

Reaction of 2-Methylcyclohexanone with CS in AcOH. A mixture of 2-methylcyclohexanone (**2e**) (0.224 g, 2.00 mmol) and CS (2.013 g, 5.00 mmol) in AcOH (20 ml) was stirred at 80 °C under an oxygen atmosphere for 7 h. The white precipitate was filtered, and after evaporation of AcOH, diethyl ether (40 ml) was added to the oily residue. The solution was extracted with an aq sodium hydrogencarbonate solution (10%; 2×10 ml), and then acidified to pH 1 with HCl (10 mol dm^{-3}). Brine was added to the resultant mixture. The combined aq solution was extracted with diethyl ether (2×25 ml) and the ethereal layer was dried by sodium sulfate and concentrated in vacuum. The resulting oil was 6-oxoheptanoic acid (**48**) (0.236 g, 82%).

Reaction of 2-Methylcyclohexanone with Copper(II) Salt in AcOH. A mixture of 2-methylcyclohexanone (**2e**) (0.224 g, 2.00 mmol) and copper(II) chloride (0.852 g, 5.00 mmol) in AcOH (20 ml) was stirred at 80 °C under an oxygen atmosphere for 5 h. After the usual work up, the resulting oil was 6-oxoheptanoic acid (**48**) (0.248 g, 86%).

Propyl 6-Oxooctanoate (34): Pale-yellow oil; IR (NaCl) 1733 and 1712 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ = 4.03 (t, J = 6.7 Hz, 2H), 2.40—2.46 (m, 4H), 2.32 (t, J = 6.6 Hz, 2H), 1.60—1.68 (m, 6H), 1.05 (t, J = 7.2 Hz, 3H), and 0.94 (t, J = 7.2 Hz, 3H); ^{13}C NMR ($CDCl_3$) δ = 211.1, 173.5, 65.9, 41.9, 35.9, 34.1, 24.5, 23.3, 22.0, 10.4, and 7.8; MS (EI) m/z 200 (M^{+}), 140, 129, 95, and 73; MS (CI) m/z 201([M+1]$^{+}$).



1a, 2a, 3a, 4a, 1e, 2e, 2f, 2g, 2i, 2j, 2k **47, 48, 49, 50, 51, 52, 53** **43, 44, 45, 46**

Table 5. Oxidative Cleavage Reaction of 2-Alkylcycloalkanone with CS and $CuCl_2 \cdot 2H_2O$[a)]

Run	Substrate	CS or $CuCl_2 \cdot 2H_2O$	Time (h)	Product (%)[b)]
1	**1a**	CS	8	**43** (82)
2	**1a**	$CuCl_2 \cdot 2H_2O$	6	**43** (84)
3	**2a**	CS	8	**44** (86)
4	**2a**	$CuCl_2 \cdot 2H_2O$	6	**44** (79)
5	**3a**	CS	8	**45** (86)
6	**3a**	$CuCl_2 \cdot 2H_2O$	6	**45** (82)
7	**4a**	CS	8	**46** (80)
8	**4a**	$CuCl_2 \cdot 2H_2O$	6	**46** (82)
9	**1e**	CS	8	**47** (88)
10	**1e**	$CuCl_2 \cdot 2H_2O$	4	**47** (96)
11	**2e**	CS	7	**48** (82)
12	**2e**	$CuCl_2 \cdot 2H_2O$	5	**48** (86)
13	**2f**	CS	6	**49** (85)
14	**2f**	$CuCl_2 \cdot 2H_2O$	6	**49** (81)
15	**2g**	CS	8	**50** (85)
16	**2g**	$CuCl_2 \cdot 2H_2O$	12	**50** (82)
17	**2i**	CS	6	**51** (80)
18	**2i**	$CuCl_2 \cdot 2H_2O$	6	**51** (83)
19	**2j**	CS	8	**52** (78)
20	**2j**	$CuCl_2 \cdot 2H_2O$	8	**52** (84)
21	**2k**	CS	5	**53** (88)
22	**2k**	$CuCl_2 \cdot 2H_2O$	5	**53** (84)
23	Camphor	CS	5	No reaction
24	Camphor	$CuCl_2 \cdot 2H_2O$	5	No reaction

a) Reaction conditions: substrate (2.0 mmol), CS (5.0 mmol), and acetic acid (20 ml) were employed.

Propyl 6-Oxononanoate (35): Pale-yellow oil; IR (NaCl) 1735 and 1712 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 4.03 (t, J = 6.6 Hz, 2H), 2.41 (t, J = 5.6 Hz, 2H), 2.37 (t, J = 5.5 Hz, 2H), 2.32 (t, J = 7.3 Hz, 2H), 1.57—1.68 (m, 8H), and 0.89—0.96 (m, 6H); ^{13}CNMR ($CDCl_3$) δ = 210.9, 173.6, 66.0, 44.8, 42.3, 34.1, 24.5, 23.2, 22.0, 17.3, 13.8, and 10.4; MS (EI) m/z 214 (M^+), 186, 155, 129, 87, and 71; MS (CI) m/z 215 ($[M+1]^+$).

Isopropyl 5-Oxohexanoate (37): Pale-yellow oil; IR (NaCl) 1738 and 1718 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 5.00 (sept, J = 6.2 Hz, 1H), 2.51 (t, J = 7.2 Hz, 2H), 2.30 (t, J = 7.3 Hz, 2H), 2.15 (s, 3H), 1.85—1.92 (m, 2H) and 1.23 (d, J = 6.6 Hz, 6H); ^{13}CNMR ($CDCl_3$) δ = 208.1, 172.7, 67.6, 42.5, 33.6, 29.9, 21.9, 21.9, and 19.0; MS (EI) m/z 172 (M^+), 113, and 71; MS (CI) m/z 173 ($[M+1]^+$).

Isopropyl 6-Oxononanoate (39): Pale-yellow oil; IR (NaCl) 1731 and 1180 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 5.00 (sept, J = 6.2 Hz, 1H), 2.42 (t, J = 6.0 Hz, 2H), 2.38 (q, J = 7.3 Hz, 2H), 2.26—2.29 (m, 2H), 1.55—1.64 (m, 6H), 1.23 (d, J = 6.2 Hz, 6H), and 0.91 (t, J = 1.8 Hz, 3H); ^{13}CNMR ($CDCl_3$) δ = 210.9, 173.0, 67.5, 44.8, 42.3, 34.4, 24.6, 23.2, 21.9, 21.9, 17.3, and 13.8; MS (EI) m/z 214 (M^+), 155, 129, and 87; MS (CI) m/z 215 ($[M+1]^+$).

Isopropyl 6-Phenyl-6-oxohexanoate (40): Colorless oil; IR (NaCl) 1685 and 1108 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 7.94 (d, J = 7.1 Hz, 1H), 7.51 (t, J = 6.6 Hz, 1H), 7.42 (t, J = 7.1 Hz, 1H), 7.30 (t, J = 6.6 Hz, 1H), 7.12 (d, J = 7.1 Hz, 1H), 4.90 (sept, J = 6.2 Hz, 1H), 2.96 (t, J = 7.3 Hz, 2H), 2.31 (t, J = 7.0 Hz, 2H), 1.71—1.80 (m, 4H), and 1.21 (d, J = 6.2 Hz, 6H); ^{13}CNMR ($CDCl_3$) δ = 199.7, 172.9, 136.9, 132.9, 128.6, 128.0, 67.4, 38.1, 34.4, 24.6, 23.6, 21.8, and 14.1; MS (EI) m/z 248 (M^+), 189, 143, and 77; MS (CI) m/z 249 ($[M+1]^+$).

***t*-Butyl 6-Oxoheptanoate (41):** Pale-yellow oil; IR (NaCl) 1732 and 1719 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 2.45 (t, J = 6.6 Hz, 2H), 2.22 (t, J = 7.0 Hz, 2H), 2.14 (s, 3H), 1.57—1.60 (m, 4H), and 1.44 (s, 9H); ^{13}CNMR ($CDCl_3$) δ = 208.7, 172.8, 80.2, 43.3, 35.3, 29.9, 28.1, 28.1, 28.1, 24.5, and 23.2; MS (EI) m/z 200 (M^+), 144, 127, 109, and 57; MS (CI) m/z 201 ($[M+1]^+$).

1-Methyl-2-propoxynaphthalene (56c): Plates; mp 34.8—36.2 °C; IR (KBr) 1625 and 1089 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 7.90 (d, J = 8.8 Hz, 1H), 7.72 (d, J = 8.4 Hz, 1H), 7.61 (d, J = 9.2 Hz, 1H), 7.41—7.45 (m, 1H), 7.27—7.31 (m, 1H), 7.16 (d, J = 9.2 Hz, 1H), 3.96 (t, J = 6.6 Hz, 2H), 2.54 (s, 3H), 1.78—1.83 (m, 2H), and 1.04 (t, J = 4.2 Hz, 3H); ^{13}CNMR ($CDCl_3$) δ = 153.9, 133.8, 129.1, 128.3, 127.0, 126, 123.5, 123.2, 119.7, 115.1, 71.2, 23.0, 10.7, and 10.6; MS (EI) m/z 200 (M^+), 158, 128, 115, and 77; MS (CI) m/z 201 ($[M+1]^+$).

Propyl 3-(2-Acetylphenyl)propanoate (57b): Colorless oil; IR (NaCl) 1734 and 1685 cm^{-1}; ^1HNMR ($CDCl_3$) δ = 7.26—7.72 (m, 4H), 4.01 (t, J = 7.0 Hz, 2H), 3.17 (t, J = 7.7 Hz, 2H), 2.65 (t, J = 7.7 Hz, 2H), 2.59 (s, 3H), 1.59—1.64 (m, 2H), and 0.90 (t, J = 7.4 Hz, 3H); ^{13}CNMR ($CDCl_3$) δ = 201.6, 173.2, 141.0, 137.5, 131.8, 131.5, 129.6, 126.4, 66.0, 35.8, 29.6, 29.6, 22.0, and 10.4; MS (EI) m/z 234 (M^+), 175, 159, 131, and 77; MS (CI) m/z 235 ($[M+1]^+$).

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