Pergamon

Tetrahedron Letters 40 (1999) 6791–6794

TETRAHEDRON LETTERS

Novel self-coupling reaction of cyclic ketones under a high-pressure mercury lamp

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Received 9 March 1999; revised 8 July 1999; accepted 9 July 1999

Abstract

A novel self-coupling reaction in alcohol or hexane–water of cycloalkanone (cycloheptanone, cyclooctanone, and cyclododecanone) with irradiation under a high-pressure mercury lamp yielded the corresponding pinacol-type compound in good yields. In the case of cyclohexanone, 2-methyl-, 2-phenyl-, 4-methylcyclohexanone, 5α- and 5β-cholestan-3-one, the pinacol derivatives were not obtained and the dimethyl acetals were given. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: cyclic ketones; photochemistry; coupling reactions; cross-coupling reactions; diols.

Pinacol-type 1,2-diol can be synthesized by reduction of ketones and aldehydes with active metals (sodium, magnesium, or aluminum),[1] Mg–MgI_2,[2] SmI_2,[3] Ce–I_2,[4] Yb,[5] and a reagent prepared from TiC14 and Mg amalgam.[6] Some of these methods, unfortunately, are associated with the use of toxic reagents and heavy metals. From the viewpoint of green chemistry, it has been reported that the dimerization of ketones to 1,2-diols is accomplished by photochemical methods. These methods usually involve irradiation of aromatic aldehydes and dialkyl ketones under a high-pressure mercury lamp in the presence of a hydrogen donor such as 2-propanol, toluene, or amine.[7]

The pinacol-type 1,2-diols of cycloalkanone are usually prepared by one of the following methods: reduction of ketone in THF with [Mg–Hg]/$TiCl_4$,[8] the reaction of magnesium atoms with cycloheptanone,[9] pinacolization of cyclohexanone using samarium(II) bromide,[10] and reductive coupling of carbonyl compounds to pinacols using low-valent cerium.[4] However, these methods are not applicable to cyclododecanone. Nickon and Zurer reported that reductive coupling of cyclododecanone with $TiCl_4$ and Zn in THF and pyridine gave 1,1-bicyclododecanol (16%).[11] Here we report that the irradiation reaction of cycloalkanone [cyclohexanone (**1**), cycloheptanone (**2**), cyclooctanone (**3**), cyclodecanone (**4**), cyclododecanone (**5**), 2-methyl- (**6**), 2-phenyl- (**7**), and 4-methylcyclohexanone (**8**), 5α- (**9**), and 5β-cholestan-3-one (**10**)] in methanol under a nitrogen atmosphere with a high-pressure mercury lamp (λ

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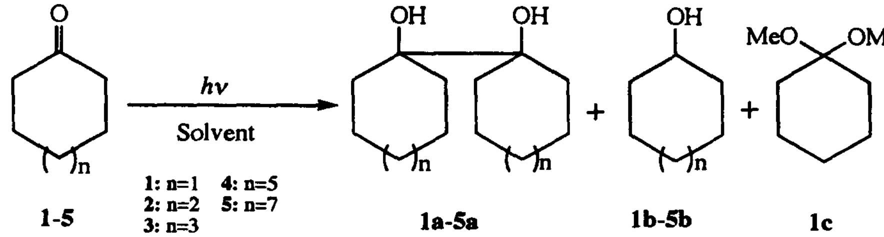
PII: S0040-4039(99)01357-X

Table 1
Photochemical coupling reaction of cycloalkanone at room temperature

Substrates[a]	Solvent	Method	Time (h)	Products[b](Yields,%)[c]
Cyclohexanone(**1**)	MeOH	400W	4	No Reaction
	MeOH	100W	18	**1c** (92)
	MeOH[d]	100W	22	**1c** (73)
	i-PrOH	100W	20	**1b** (62)
Cycloheptanone(**2**)	MeOH	400W	4	**2a** (71), **2b**(15)
Cyclooctanone(**3**)	MeOH	400W	8	**3a** (76)
Cyclodecanone(**4**)	MeOH	400W	12	**4b** (65)
Cyclododecanone(**5**)	MeOH	100W	4	**5a** (84), **5b** (8)
	MeOH	400W	3	**5a** (85), **5b** (9)
	EtOH	100W	8	**5a** (79), **5b** (10)
	EtOH	400W	6	**5a** (82), **5b** (10)
	Hexane	400W	4	No Reaction
	Hex-H_2O	400W	4	**5a** (81), **5b** (8)
	Cyclohex-H_2O	400W	10	**5a** (79), **5b** (8)
2-Methylcyclohexanone(**6**)	MeOH	100W	18	Dimethyl Acetal(**6c**) (76)
2-Phenylcyclohexanone(**7**)	MeOH	100W	30	Dimethyl Acetal(**7c**) (33)
4-Methylcyclohexanone(**8**)	MeOH	100W	18	Dimethyl Acetal(**8c**) (91)
5α-Cholestan-3-one(**9**)	MeOH	400W	12	Dimethyl Acetal(**9c**) (87)
5β-Cholestan-3-one(**10**)	MeOH	400W	10	Dimethyl Acetal(**10c**) (85)

a) Substrate (3.23 mmol) in alcohol (200 ml) was employed. b) All products displayed satisfactory spectral data(IR, ^{1}H-NMR, ^{13}C-NMR, and MS). c) Isolated yield. d) MeOH: H_2O=20:1.

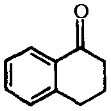
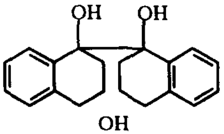
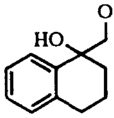
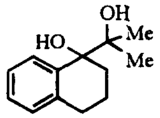
>300 nm) at room temperature yielded the corresponding pinacol-type 1,2-diols, acetals and alcohols. The irradiation of cyclododecanone (**5**) in methanol at room temperature under a nitrogen atmosphere with a 400 W mercury lamp for 4 h gave 1,1-bicyclododecanol (**5a**) (84%)[12] and cyclododecanol (**5b**) (8%). These results are summarized in Table 1.



1-5   **1**: n=1 **4**: n=5 **2**: n=2 **5**: n=7 **3**: n=3   **1a-5a**   **1b-5b**   **1c**

As can be seen from Table 1, it was found that this method is applicable to cycloalkanone, but there is some limitation on its use in some cases. Cyclohexanone (**1**), 2-methyl- (**6**) and 2-phenylcyclohexanone (**7**), 4-methylcyclohexanone (**8**), 5α- (**9**) and 5β-cholestan-3-one (**10**) were not converted into the corresponding pinacols but into dimethyl acetal **1c**, **6c**, **7c**, **8c**, **9c** and **10c** in 92, 76, 33, 91, 87 and

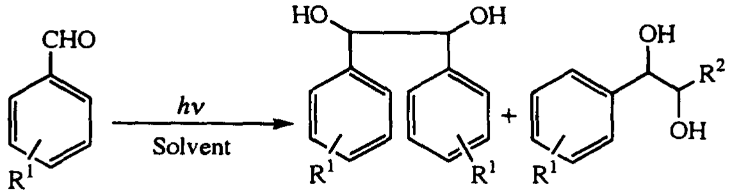
Table 2
Photochemical coupling reaction of benzaldehyde at room temperature

Substrate	Solvent	Method	Time(h)	Products[a](Yields,%)[b]
11	MeOH	100W	3	**11a** (31) (dl/meso=50/50) **11d** (69)
	MeOH	400W	2	**11a** (32) (dl/meso=48/52) **11d** (68)
	EtOH	100W	3	**11a** (49) (dl/meso=55/45) **11e** (51) (dl/meso=55/45)
	PrOH	100W	10	**11a** (58) (dl/meso=52/48) **11f** (42) (dl/meso=50/50)
	i-PrOH	100W	15	**11a** (69) (dl/meso=56/44) **11g** (31)
	H_2O	400W	10	**11a** (39) (dl/meso=50/50)
12	MeOH	400W	2	**12a** (15) (dl/meso=54/46) **12d** (85)
13	MeOH	400W	10	**13d** (85)
 **14**	MeOH	100W	18	 **14a** (17)  **14d** (80)
14	i-PrOH	100W	12	**14a** (67)  **14g** (29)

a) All products displayed satisfactory spectral data(IR,^{1}H-NMR,^{13}C-NMR, and MS). b)Almost quantitative yields of the pinacol and the cross-coupling diols were obtained. The composition of the reaction mixture was determined from the peak area ratio of the NMR spectrum.

85% yield, respectively. It seems that acetalization occurs readily in these oxo compounds, and the acetals formed are stable and do not transform into alcohol and pinacol. In the case of cyclodecanone (**4**), cyclodecanol (**4b**) was obtained in 65% yield, and in the case of 2-propanol, **1** was transformed to cyclohexanol, not dimethyl acetal. Moreover, in the case of α-tetralone in 2-propanol, pinacol (**14a**) (67%) and cross-coupled diol (**14g**) (29%) were obtained.[13] These results are summarized in Table 2.

It is known that photoreduction of benzophenone in methanol and ethanol gives benzpinacol and a cross-coupled product.[14] Weiner reported that photoreduction of benzophenone in 2-propanol yields a pinacol-type compound and mixed pinacol, $(C_6H_5)_2C(OH)C(OH)(CH_3)_2$.[15] It seems that these reactions occur by the free ketyl radicals. It was found that the reaction of benzaldehyde (**11**) in methanol gave the cross-coupled diol, i.e. phenyl-1,2-ethanediol (**11d**; 69%) and pinacol (**11a**; 31%). However, due to the bulkiness of the alkoxyl group (methanol, ethanol, 1-propanol, and 2-propanol), it is difficult to form the cross-coupled product.



11:R^1=H
12:R^1=*p*-OMe
13:R^1=*o*-OMe

11a:R^1=H
12a:R^1=*p*-OMe

11d:R^1=H, R^2=H
11e:R^1=H, R^2=Me
11f:R^1=H, R^2=Et
11g:R^1=H, R^2=Me$_2$
12d:R^1=*p*-OMe, R^2=H
13d:R^1=*o*-OMe, R^2=H

In conclusion, the present method, although not widely applicable, has a notable characteristic which was not observed previously.[4,11] This reaction affords a new simple synthetic method for the pinacols of cycloheptanone, cyclooctanone, and cyclododecanone. It is possible to draw the following four types of reactions from this methodology: pinacol coupling reaction; reduction to alcohol; acetalization; and cross-coupling reaction. It is particularly noteworthy that this reaction is a new, clean method.

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12. Representative spectral data: **5a**: Mp 46.8–48.3°C; ^{1}H NMR (400 MHz, CDCl$_3$) δ 2.21 (br s, 2OH); ^{13}CNMR (CDCl$_3$) δ 17.06, 19.99, 22.51, 23.22, 23.32, 26.60, 27.30, 27.44, 32.83, 35.79, 48.42 and 78.88; IR (KBr) 3365, 1105 cm^{-1}. HRMS (EI): calcd for $C_{24}H_{46}O_2$: 366.3484; found: 366.3451.
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