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(6) GLC analyses were determined on a Hewlett-Packard Model 7610A (flame detector) chromatograph. The IR spectra were determined with a Beckman Model AccuLab 6 infrared recording spectrophotometer. The ^{1}H NMR spectra were determined at 100 MHz with a JEOL Model JNM-PS-FT-100 fast Fourier Transform NMR spectrometer. The chemical shifts are expressed in δ values (parts per million) relative to a Me_4Si internal standard. The mass spectra were determined with a Finnigan Model 3100D mass spectrometer (70 eV) to which was interfaced a Varian Associates Model 1400 gas chromatograph.

(7) During the addition the exothermic reaction was moderated (18–25 °C, internal thermometer) with a water bath.

(8) To increase the efficiency of the condensation process, the reaction vessel was cooled (dry ice–acetone bath), and to prevent splattering, the apparatus was tilted slightly to allow the condensing ammonia to run down the walls of the flask.

(9) The NH_4Cl is most conveniently introduced by attaching a glass bulb filled with the salt to a side arm by means of tygon tubing. When the salt is to be added, the bulb is raised and tapped gently to smoothly introduce the quenching agent. Should this step start to become violent, the addition and sometimes even the vigorous stirring should be momentarily stopped to avoid an eruption.

Oxidation of Olefins with Silver Chromate–Iodine. A New and Facile Synthesis of α-Iodo Ketones

Giuliana Cardillo* and Makoto Shimizu[1]

Istituto Chimico "G.Ciamician", Università di Bologna
Via Selmi 2,40126 Bologna, Italy

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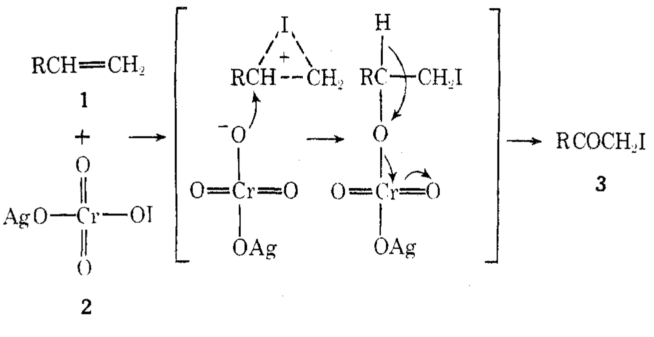
Our interest in the nucleophilic properties of chromate anion coupled with the recent attention accorded to the oxidation of activated alkyl halides to the corresponding aldehydes[2] prompts this report on the capability of the silver chromate–iodine system for the facile oxidation of double bonds to the corresponding α-iodo ketones.

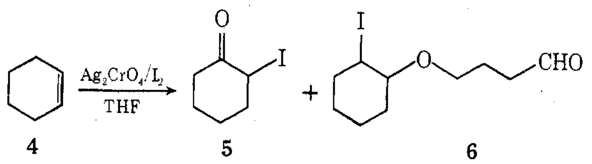
α-Halo ketones have been regarded as synthetically useful materials and several general methods for their syntheses have been established.[3] In contrast to their chloro or bromo analogues, α-iodo ketones, however, have not been sufficiently studied. This is partly because of their relative instability and that there are only a few satisfactory synthetic methods available, e.g., halogen–iodide interchange[4] and treatment of enol acetates with *N*-iodosuccinimide.[5] Furthermore, both methods appeared to need relatively high reaction temperatures which might cause decomposition of the products. It is, therefore, of value to develop an easy and mild synthetic route to α-iodo ketones.

Until now, for one-step oxidations of olefins to α-chloro ketones only two methods have been known, one utilizing nitrosyl chloride[6a,b] and the other chromyl chloride.[6c] On the other hand, oxidation of alkenes with acyl hypoiodite provides an easy way to introduce α-iodo alcohols to double bonds.[7] In an analogy to the well-known Prevost reaction, we considered that the generation of a hypoiodous–chromic acid mixed anhydride (**2**) under mild conditions would lead to a one-step oxidation of olefins to α-iodo ketones. Scheme I reports a possible mechanism.

Scheme I



Scheme II



We have now found that the treatment of cyclohexene with silver chromate[8] and iodine leads to 2-iodocyclohexanone. A series of experiments was carried out in an effort to find the optimum conditions for the oxidation of cyclohexene. Table I lists the results obtained.

When THF was used as a solvent, a small amount of ether **6**[9] arising from THF was always recovered together with 2-iodocyclohexanone (**5**).

As shown in Table I, the best yield was obtained when dichloromethane was used as a solvent in the presence of 0.5 to 1.0 equiv of pyridine.[10] The reactions summarized in Table II (vide infra) were performed under the optimum conditions found for cyclohexene.

This reaction seemed to have wide applicability. In general, electron-rich olefins gave better results, while electron-deficient ones such as crotononitrile resulted in the recovery of the starting olefins. Aliphatic, alicyclic, and aromatic olefins gave satisfactory yields in the majority of cases. The lower yields observed in the cases of allyl benzoate and 2,3-dihydro-4*H*-pyran are due to the formation of the unidentified by-products which decomposed despite several attempts for isolation. Further, terminal olefins were converted exclusively to the corresponding α-iodo ketones.

Thus, the above results as well as mild reaction conditions make the present method highly useful for the synthesis of α-iodo ketones from olefins.

Further studies utilizing other metal chromates are currently in progress.

Experimental Section

General. All reactions were run under a positive pressure of dry argon. Infrared spectra (IR) were recorded on a Perkin-Elmer 710B spectrometer and are given in cm^{-1}. Nuclear magnetic resonance spectra (NMR) were determined on a Perkin-Elmer R12B spectrometer. Chemical shifts are given in ppm from internal tetramethylsilane. Mass spectra (MS) were taken on a Varian MAT 111 (70 eV). Melting points (mp) which were determined in glass capillaries and boiling points (bp) were uncorrected. Preparative thin-layer chromatography (TLC) was carried out on a glass plate (20 × 20 cm) coated with Merck silica gel HF_{254} (1-mm thick). Columun chromatography was performed on Merck silica gel (0.05–0.20 mesh).

Tetrahydrofuran (THF) and dimethoxyethane (DME) were distilled from sodium benzophenone ketyl immediately before use. Benzene was distilled from sodium and stored over it. Dichloromethane was distilled from phosphorus pentoxide and stored over 4-Å molecular sieves. Pyridine was distilled from calcium hydride and stored under argon.

Silver Chromate.[8] A solution of silver nitrate (17.0 g, 100 mmol) in 200 mL of water was added with stirring to a solution of potassium chromate (9.7 g, 50 mmol) in 200 mL of water. Promptly and quantitatively reddish-brown silver chromate precipitated. The precipitate was filtered, washed successively with water, dried in vacuo, finely pulverized, and dried again in vacuo at 90 °C for 5 h.

Unless otherwise indicated, the following α-iodo ketones were prepared according to the general procedure.

Phenacyl Iodide (General Procedure). To a suspension of silver chromate (1.10 g, 3.3 mmol) and 4-Å molecular sieves[11] (1.5 g) in 15 mL of dichloromethane were added iodine (1.14 g, 4.5 mmol) and a solution of pyridine (118 mg, 1.5 mmol) in 0.75 mL of dichloromethane at 0 °C and stirred for 5 min.

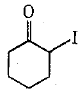
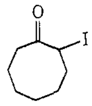
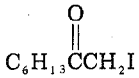
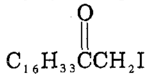
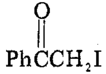
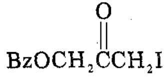
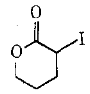
A solution of styrene (312 mg, 3.0 mmol) in 5 mL of dichloromethane was added dropwise during 5 min to the ice-cooled suspen-

Table I. Oxidation of Cyclohexene: Comparison of Reaction Conditions[a]

Entry	Ag_2CrO_4, equiv	I_2, equiv	Solvent	React. condns, °C (period, min)	Yield,[b] %	
					5	6
1	2.0[c]	1.0	THF	0 (30), rt (30)	35	10
2	3.0	1.0	THF	−10 (10), 0 (50)	41	18
3	3.0	1.0	THF	0 (5), rt (90)	52	26
4	6.0	1.0	THF	0 (10), rt (60)	61[d]	15[d]
5	3.0	1.0	DME	0 (180), rt (240)	40	
6	3.0[c,e]	1.0	C_6H_6	rt (60)	46	
7	1.1[c,e]	1.1	CH_2Cl_2	0 (20), rt (40)	51	
8	2.0[c,e]	1.1	CH_2Cl_2	0 (5), rt (60)	65	
9	1.1[c,f]	1.5	CH_2Cl_2	0 (15), rt (45)	63	
10	1.1[c,f]	1.5	CH_2Cl_2	0 (30), rt (60)	60[d]	

[a] Reactions were carried out in 1-mmol scale. [b] Yield determined by NMR using pyrazine or 1,1,2,2-tetrachloroethane as internal standard. [c] Molecular sieves (0.5 g) were used. [d] Isolated yield. [e] In the presence of pyridine (1.0 equiv). [f] In the presence of pyridine (0.5 equiv).

Table II. Oxidation of Olefins with Silver Chromate–Iodine[a]

Entry	Olefin	Registry no.	α-Iodo ketone,[b]	Registry no.	Yield,[c] %
11	Cyclohexene	110-83-8		35365-19-6	60
12	Cyclooctene	931-88-4		63641-49-6	65
13	1-Octene	111-66-0	 $C_6H_{13}\overset{O}{\overset{\parallel}{C}}CH_2I$	63641-50-9	74
14	1-Octadecene	112-88-9	 $C_{16}H_{33}\overset{O}{\overset{\parallel}{C}}CH_2I$	63641-51-0	65
15	Styrene	100-42-5	 $Ph\overset{O}{\overset{\parallel}{C}}CH_2I$	4636-16-2	86
16	Cinnamyl acetate	103-54-8	 $Ph\overset{O}{\overset{\parallel}{C}}CHICH_2OAc$	63641-52-1	82
17	Allyl benzoate	583-04-0	 $BzOCH_2\overset{O}{\overset{\parallel}{C}}CH_2I$	27933-28-4	49
18	2,3-Dihydro-4*H*-pyran	110-87-2		63641-53-2	39

[a] Reactions were carried out in 2–3-mmol scale. [b] All products were characterized by IR, NMR, and mass spectra. [c] Isolated yield.

sion, which was stirred for 20 min at 0 °C. Then, the cooling bath was removed and the reaction mixture was stirred for an additional hour at room temperature.

The dark-brown mixture was filtered through a pad of Celite. The filtrate was washed with 5% aqueous $Na_2S_2O_3$ and saturated aqueous NaCl, and dried ($MgSO_4$). The crude product (668 mg) obtained after concentration was purified on column chromatography (ca. 20 g of silica gel: elutant, hexane/ether 90/10)[12] to give the title compound (636 mg, 86%) as a slightly yellow oil, which on cooling crystallized: mp (hexane) 34.0–34.5 °C;[13] IR (neat) 1685 cm^{-1} (vs, C=O); NMR (CCl_4) 4.25 (s, 2 H, CH_2ICO–), 7.28–7.65 (m, 3 H, aromatic), 7.87–8.10 ppm (m, 2 H, aromatic); MS *m/e* (rel intensity) 246 ($M^{+\cdot}$, 18), 119 ($M^{+\cdot}$ –I, 13), 105 ($M^{+\cdot}$ –CH_2I, 20), 77 (Ph^+, 100), 51 ($M^{+\cdot}$ –$C_2H_2COH_2I$, 40).

2-Iodocyclohexanone. The reaction was carried out in a 2-mmol scale, and the title compound (268 mg, 60%) was obtained: bp 54 °C/1 mm;[14] IR (neat) 1710 cm^{-1} (vs, C=O); NMR (CCl_4) 1.50–2.55 (m, 8 H, –CH_2–, –CH_2CO–), 4.45–4.70 ppm (m, 1 H, –CHICO–); MS *m/e* (rel intensity) 224 ($M^{+\cdot}$ 67), 97 ($M^{+\cdot}$ –I, 100), 55 ($M^{+\cdot}$ –C_3H_6I, 100), 42 ($M^{+\cdot}$ –C_3H_3OI, 36).

2-Iodocyclooctanone. The reaction was carried out in 3-mmol scale, and the title compound (429 mg, 65%) was obtained: bp 58 °C/1.5 mm; IR (neat) 1700 cm^{-1} (vs, C=O); NMR (CCl_4) 1.15–2.60 (m, 12 H, –CH_2–, –CH_2CO–), 4.50 ppm (dd, 1 H, J = 13 and 5.5 Hz, –CHICO–); MS *m/e* (rel intensity) 252 ($M^{+\cdot}$ 11), 125 ($M^{+\cdot}$ –I, 22), 70 ($M^{+\cdot}$ –C_3H_3OI, 8), 55 ($M^{+\cdot}$ –C_5H_5I, 100).

1-Iodo-2-octanone. The reaction was carried out in 3-mmol scale, and the title compound (566 mg, 74%) was obtained: bp 63 °C/1 mm; IR (neat) 1715 cm^{-1} (vs, C=O); NMR (CCl_4) 0.75–1.75 (m, 13 H, –CH_2–, –CH_3), 2.67 (t, 2 H, J = 7 Hz, –CH_2CO–), 3.70 ppm (s, 2 H, CH_2ICO–); MS *m/e* (rel intensity) 254 ($M^{+\cdot}$ 9), 184 ($M^{+\cdot}$ –C_5H_{10}, 20), 169 ($M^{+\cdot}$ –C_6H_{13}, 8), 127 ($M^{+\cdot}$ –I, 23), 113 ($M^{+\cdot}$ –CH_2I, 100), 85 ($M^{+\cdot}$ –$COCH_2I$, 59).

1-Iodo-2-octadecanone. The reaction was carried out in 3-mmol scale, and unreacted 1-octadecene (20 mg, 3%) and the title compound (765 mg, 65%) was obtained: mp 66–66.5 °C (hexane); IR (nujol) 1715 cm^{-1} (vs, C=O); NMR ($CDCl_3$) 0.75–1.75 (m, 31 H, –CH_2–, –CH_3), 2.72 (t, 2 H J = 7 Hz, –CH_2CO–), 3.78 ppm (s, 2 H, CHICO–); MS *m/e* (rel intensity) 267 ($M^{+\cdot}$ –I, 100), 253 ($M^{+\cdot}$ –CH_2I, 67), 225 ($M^{+\cdot}$ –$COCH_2I$, 3), 184 ($M^{+\cdot}$ –$C_{15}H_{30}$, 66), 169 ($M^{+\cdot}$ –$C_{16}H_{33}$, 20).

2-Iodo-3-oxo-3-phenylpropyl Acetate. The reaction was carried out on a 2-mmol scale, and the title compound (520 mg, 82%) was obtained: mp 56–57 °C (CCl_4) dec; IR (nujol) 1740 (vs, –O–C=O), 1670 cm^{-1} (vs, C=O); NMR (CCl_4) 1.93 (s, 3 H, –CH_3CO–), 4.55 (d, 2 H, J = 7.5 Hz, –CHO–), 5.53 (t, 1 H, J = 7.5 Hz, –CHICO–), 7.20–7.65 (m, 3 H, aromatic), 7.90–8.12 ppm (m, 2 H, aromatic); MS *m/e* (rel intensity) 191 ($M^{+\cdot}$ –I, 14), 105 ($PhCO^+$, 100), 106 ($PhCHO^+$, 9), 60 (CH_3COOH^+, 9), 43 (CH_3CO^+, 9).

3-Iodo-2-oxopropyl Benzoate. The reaction was carried out in 2-mmol scale. The crude product was purified on TLC to give unreacted allyl benzoate (55 mg, 17%), and the title compound was obtained (229 mg, 49%): mp 77–77.5 °C (hexane); IR (nujol) 1735 (vs, –O–C=O), 1715 cm^{-1} (vs, C=O); NMR ($CDCl_3$) 3.96 (s, 2 H, CH_2ICO–), 5.20 (s, 2 H, –OCH_2CO–), 7.50–7.80 (m, 3 H, aromatic), 8.21–8.35 ppm (m, 2 H, aromatic); MS *m/e* (rel intensity) 304 ($M^{+\cdot}$ 2), 177 ($M^{+\cdot}$ –I, 16), 169 (CH_2ICO^+, 1), 135 ($M^{+\cdot}$ –$COCH_2I$, 4), 106 ($PhCHO^+$, 11), 105 ($PhCO^+$, 100), 77 (Ph^+, 46).

α-Iodo-δ-valerolactone. The reaction was carried out in 2-mmol scale using 1.2 equiv of iodine, and the crude product was purified on TLC to give the title compound (175 mg, 39%): bp 80–82 °C/1.5 mm; IR (neat) 1730 cm^{-1} (vs, C=O); NMR (CCl_4) 1.70–2.45 (m, 4 H, –CH_2–), 4.37–4.64 (m, 2 H, –OCH_2–), 4.86 ppm (t, 1 H, J = 5 Hz, –CHICO–); MS *m/e* (rel intensity) 226 ($M^{+\cdot}$ 28), 196 ($M^{+\cdot}$ –CH_2O, 11), 127 (I^+, 32), 99 ($M^{+\cdot}$ –I, 20), 55 ($COCHCH_2^+$, 100).

Registry No.—2, 63641-54-3; **6,** 63641-55-4; silver chromate, 19247-15-5; iodine, 7553-56-2.

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(9) The structure of **6** was inferred on the basis of its spectral properties: IR (neat) 1725 cm^{-1} (vs, C=O); NMR (CCl_4) 0.80–2.30 (m, 10 H), 2.55 (t, 2 H, J = 6 Hz), 3.20–3.70 (m, 3 H), 3.75–4.30 (m, 1 H), 9.80 ppm (br s, 1 H); MS *m/e* (rel intensity) 296 ($M^{+\cdot}$ 1), 267 (1), 252 (2), 209 (4), 169 (3), 87 (24), 71 (100), 57 (9), 43 (56), 29 (17).

(10) The role of pyridine is presumably that of facilitating the formation of the supposed hypoiodous–chromic acid mixed anhydride: In fact, an addition of pyridine to the silver chromate–iodine mixture caused an immediate change of color.

(11) To ensure dryness of silver chromate, the use of molecular sieves is preferable.

(12) Because of the less stable nature of the product, both a short column and rapid elution are recommendable.

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Photochemistry of a Ketone with a Reportedly High Circular Dichroism Using Circularly Polarized Light

J. F. Nicoud, C. Eskenazi, and H. B. Kagan*

Laboratoire de Synthèse Asymétrique, LA CNRS No. 040255, Université de Paris-Sud, 91405-Orsay, France

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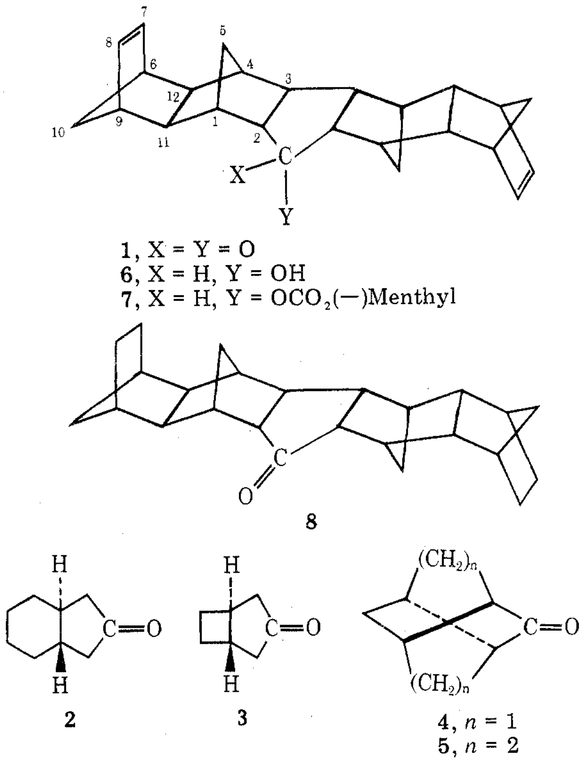
Partial photoresolution with circularly polarized light (CPL) is useful in the determination of the anisotropy factor (*g* factor = $\Delta\epsilon/\epsilon$) of chiral compounds. This easily available test led us to reinvestigate the previously described[1] chiroptical properties of ketone 1.

Partial photodecomposition of a racemic mixture with CPL was first realized by Kuhn.[2] We reinvestigated this field in 1974 and gave a kinetic treatment permitting the prediction of the optical purity of the remaining material (characterized by its *g* factor) for a given fraction of destruction.[3] With *dl*-camphor (g = 0.09, λ 310 nm) 99% destruction allowed us to recover optically active camphor with 20% enantiomeric excess (e.e.).

Scheme I



1, X = Y = O
6, X = H, Y = OH
7, X = H, Y = OCO_2(—)Menthyl

8

2 **3** **4**, *n* = 1
5, *n* = 2

This method can be useful for obtaining, for the first time, a chiral compound if classical resolution methods fail but, of course, either a high *g* factor or a high degree of photodestruction is necessary if reasonable optical purities are needed. Therefore, very little of the unphotolyzed starting material is obtained, and it must be separated and purified from a huge mass of photodecomposition products. In addition, we pointed out[3] that with a few independent experiments it should be possible to calculate the *g* factor and specific rotation of the optically pure compound.[4]

Our attention was drawn by a report[1] describing the resolution and chiroptical properties of ketone 1. From the published data, *g* factor values can be calculated at several wavelengths: g = 0.77 (322 nm), g = 0.70 (312 nm), and g = 0.65 (301 nm). These values can be compared with those of all known polycyclic ketones and even with other organic compounds.[5] For example, some of the highest known *g* factor values are 0.24 (313 nm), 0.20 (311 nm), 0.12 (286 nm), and 0.30 (288 nm) for the chiral twisted ketones **2–5**,[6–9] respectively.

It thus appears that for 1 the CD and *g* values are exceptionally high. This might be the consequence of high twist of the cyclopentanone unit, as shown by a recent report about ketones **2** and **3**.[10]

These considerations led us to investigate the promising photochemistry of ketone 1 with CPL. Computations with g = 0.80 showed that 90% and 99% decomposition should allow the recovery of 1 in 81% and 99% e.e.,[3] respectively, making this method very competitive with the previously described resolution involving formation of diastereomers.[1]

Results and Discussion

The partial photoresolution with CPL of ketone 1 is very disappointing; enantiomeric enrichment is smaller than expected and is in agreement with an average *g* factor of 0.10. Photoproducts[11] could possibly arise from an energy transfer mechanism which would change the basis of our previous calculations (Scheme II).[3] Before considering this hypothesis, we reinvestigated the chiroptical properties of ketone **1**. LAH reduction of *dl*-1 quantitatively gave *dl*-**6**. Treatment by