Anal. Calcd for $C_{23}H_{31}NO_7P_2$: C, 55.76; H, 6.26; N, 2.83; P, 12.53. Found: C, 56.45; H, 6.39; N, 2.80; P, 12.40.

Registry No.—**10**, 19656-30-5; **12**, 19656-31-6; **14**, 19656-32-7; **15**, 19656-33-8; **16**, 19656-34-9; **17**, 19656-35-0; **18**, 19656-36-1; **19**, 19656-37-2; **20**, 19656-38-3; **21**, 19656-39-4; **22**, 19656-40-7; **23**, 19656-41-8; **24**, 19656-42-9; **25**, 19656-43-0; **28**, 19656-44-1; diethyl 10-acetyl-9,10-dihydroacridine-9-phosphonate, 19656-45-2.

Acknowledgment.—The author wishes to thank Professor C. D. Gutsche and Dr. F. E. Mange for helpful discussions during the course of this work.

Dual Formation of β Diketones from Methylene Ketones and Acetic Anhydride by Means of Boron Trifluoride. Improved Method of Synthesis of Certain β Diketones[1]

Chung-Ling Mao, Frederick C. Frostick, Jr., Eugene H. Man,
Robert M. Manyik, Richard L. Wells, and Charles R. Hauser

Department of Chemistry, Duke University, Durham, North Carolina 27706

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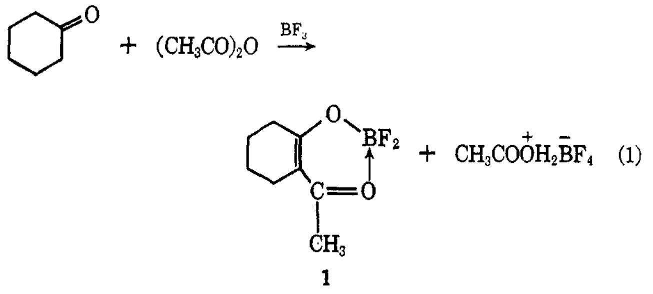
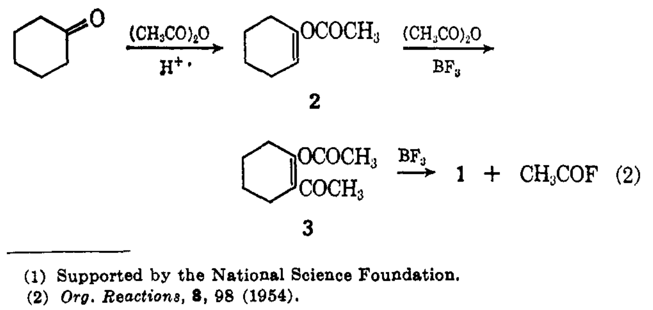
Evidence is presented that the formation of β diketones from methylene ketones and acetic anhydride by means of boron trifluoride involves, not only direct C acetylation of the ketone, but also O acetylation of the ketone and C acetylation of the resulting ketone enol ester. The O acetylation is catalyzed by proton acid formed as the by-product in the C acetylation of the ketone. Certain intermediate ketone enol esters, β diketone enol esters, and boron difluoride complexes were isolated. Acetophenone, however, apparently undergoes only C acetylation. The relative proportions of the methyl and methylene derivatives of methyl methylene ketones were found to be dependent, not only on the structure of the ketone, but also on the conditions employed for effecting the acetylation. Several β diketones were prepared conveniently by use of the boron trifluoride–diacetic acid complex which is available commercially.

In 1954,[2] the acylation of a ketone with an aliphatic anhydride by boron trifluoride to form a β diketone was suggested to involve, not only C acylation of the ketone, but also O acylation of the ketone followed by C acylation of the resulting ketone enol ester.

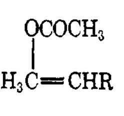
We now present evidence for such dual formation of β diketones from certain methylene ketones and acetic anhydride. Thus cyclohexanone and this anhydride were found to be converted by boron trifluoride into boron difluoride complex **1**, not only by direct C acetylation of the ketone (eq 1), but also indirectly through ketone enol acetate **2** and β diketone enol acetate **3** (eq 2). Although the second course of reaction is dependent on formation of proton acid as by-product in the first course (see eq 1 and 2), the O acetylation may be initiated soon after the boron trifluoride is added, since only a catalytic amount of the proton acid is required. The boron difluoride complex **1** was subsequently treated with hot sodium acetate solution to liberate the β diketone.





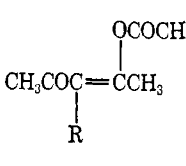
In support of the O acetylation course of reaction (eq 2), the intermediate ketone enol acetate **2** and the β diketone enol acetate **3** were isolated from the reaction mixture of cyclohexanone and acetic anhydride and subsequently converted into the boron difluoride complex **1** or 2-acetylcyclohexanone under similar conditions. In the further reaction of the β diketone enol acetate **3**, acetyl fluoride was shown to be formed as by-product (see eq 2).

Similarly, ketone enol acetates **4a** and **b** and β diketone enol acetates **5a** and **b** were isolated from the reaction mixtures of the appropriate ketones, acetic anhydride and boron trifluoride, and certain of them were subsequently converted into β diketones or their boron difluoride complexes such as **6**. Previously, certain ketone enol esters and β diketone enol esters have been converted into β diketones or their difluoride complexes; benzoyl fluoride was shown to be eliminated from a β diketone enol benzoate.[3]



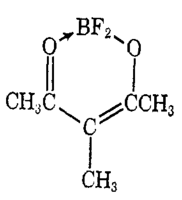
$CH_3C(OCOCH_3){=}CHR$

4a, $R = CH_3$
b, $R = n\text{-}C_4H_9$



$CH_3COC(R){=}C(OCOCH_3)CH_3$

5a, $R = CH_3$
b, $R = n\text{-}C_4H_9$



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[1] Supported by the National Science Foundation.

[2] *Org. Reactions*, **8**, 98 (1954).

[3] See C. R. Hauser, F. C. Frostick, Jr., and E. H. Man, *J. Amer. Chem. Soc.*, **74**, 3231 (1952).

Table I

Relative Proportions of Methyl (**12**) and Methylene (**13**) Derivatives of Ketones Obtained with Acetic Anhydride by Boron Ttifluoride Determined by Vpc

Ketone	Fast saturation with BF_3 gas, %		Slow saturation with BF_3 gas, %		Use of BTDA[a] complex, %	
	12	**13**	**12**	**13**	**12**	**13**
$CH_3COCH_2CH_3$	14	86	0	100	0	100
$CH_3COCH_2CH_2CH_3$	26	74	8.3 (0)[b]	91.7 (100)[b]	5 (0)[b]	95 (100)[b]
$CH_3CO(CH_2)_4CH_3$	36	64	8.4 (0)[b]	91.6 (100)[b]	0	100
$CH_3COCH_2CH(CH_3)_2$	80	20	49	51	25 (25)[b]	75 (75)[b]
$CH_3COCH(CH_3)_2$	70[c]	30[d]	37[c]	63[d]	2 (0)[b,c]	98 (100)[b,d]

[a] Boron trifluoride–diacetic acid complex. [b] Percentage obtained in the presence of catalytic amount of *p*-toluenesulfonic acid. [c] Methyl derivative **15**. [d] Methinyl derivative **16**.

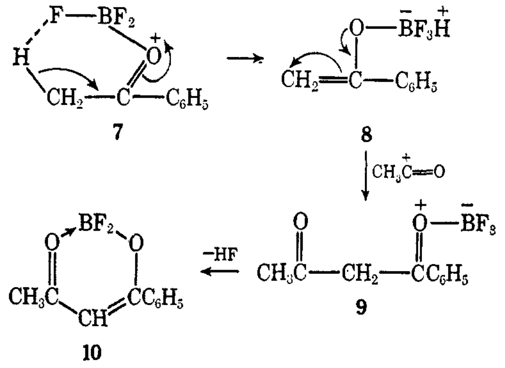
That formation of the ketone enol acetates **2** and **4a** and **b** requires the presence of proton acid (see eq 2) is supported, not only by Bedoukian's[4] preparation of such compounds from methylene ketones and acetic anhydride by means of *p*-toluenesulfonic acid, but also by our observation that the relative extent of O acetylation accompanying C acetylation of methyl methylene ketones by means of boron trifluoride is dependent upon the strength and/or amount of proton acid present (see next section).

In contrast to cyclohexanone and the other methylene ketones considered above, acetophenone underwent C acetylation with acetic anhydride in the presence of boron trifluoride apparently without appreciable O acetylation. Thus none of the enol acetate of acetophenone was isolated from, nor could any be detected by vpc in, the product obtained from this methyl ketone, acetic anhydride, and the reagent under the conditions that afforded the enol acetates of the methylene ketones **2** and **4a** and **b**. Moreover, Bedoukian[4] was unable to prepare the enol acetate of acetophenone with acetic anhydride in the presence of *p*-toluenesulfonic acid under the conditions that produced the enol acetates of certain methylene ketones.

The mechanism of direct C acetylation of acetophenone, as well as that of other ketones, probably involves the conversion of both the anhydride and ketone into reactive intermediates. The intermediate from the anhydride would presumably be a carbonium ion (as in a Friedel–Crafts acylation) and that from the ketone is suggested to be an enol-type complex such as **8**, the formation of which is perhaps initiated by hydrogen bonding as indicated in **7**. Condensation of the enol-type complex **8** with the carbonium ion would form the boron trifluoride complex of the β diketone (**9**), which eliminates hydrogen fluoride to give the boron difluoride complex **10** (Scheme I).[5]

That acetophenone was converted by boron trifluoride into an enol-type intermediate such as **8** was supported by α bromination of this ketone in the presence of this reagent but not in its absence. That the β diketone boron trifluoride complex **9** was produced as an intermediate was indicated by evolution of some hydrogen fluoride (etching of glass) from the crude reaction product to afford the relatively stable boron difluoride complex **10** (see Experimental Section).

Scheme I



Since boron trichloride and aluminum chloride have failed to effect acetylations of ketones,[6] success with boron trifluoride is suggested to be associated with a greater tendency for hydrogen bonding in the boron trifluoride complex **7** and/or a less tendency for loss of hydrogen fluoride from the enol-type complex **8** compared with those of corresponding complexes from the boron and aluminum chlorides. The presence of the negative charge on the boron in **8** should make **8** a better donor in its condensation with the carbonium ion than a neutral complex that might arise through loss of hydrogen halide.

Acetylation of Methyl Methylene Ketone.—Acetylation of methyl methylene ketones **11** by means of boron trifluoride may form the methyl and methylene derivatives **12** and **13**, and that of methyl isopropyl ketone (**14**) the methyl and methinyl derivatives **15** and **16**, respectively. The relative yields of the isomeric products obtained under various conditions are summarized in Table I.

CH_3COCH_2R **11** $CH_3COCH_2COCH_2R$ **12** $CH_3COCHRCOCH_3$ **13**

$CH_3COCH(CH_3)_2$ **14** $CH_3COCH_2COCH(CH_3)_2$ **15**

$CH_3COC(CH_3)_2COCH_3$ **16**

Table I shows that the relative proportion of the methyl and methylene derivative produced on acetylation of a methyl methylene ketone is dependent, not only on the structure of the ketone as previously observed,[7] but also on the conditions employed. Thus, with a particular methyl methylene or methyl methinyl ketone (**11** or **14**, respectively), relatively more of the methyl derivative (**12** or **15**) and relatively less of the methylene or methinyl derivative (**13** or **16**) were produced by fast saturation of the reaction mixture

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[4] P. Z. Bedoukian, *J. Amer. Chem. Soc.*, **67**, 1430 (1945).

[5] Since little etching of the glass apparatus occurred, the eliminated hydrogen fluoride was apparently converted by boron trifluoride into HBF_4, which was neutralized by the oxygen compounds to form oxonium salts.

[6] B. M. Perfetti and R. Levine, *ibid.*, **75**, 626 (1953); H. G. Walker, J. J. Sanderson, and C. R. Hauser, *ibid.*, **75**, 4109 (1953).

[7] C. R. Hauser and J. T. Adams, *ibid.*, **66**, 345 (1944).

TABLE II

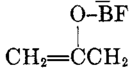
YIELDS OF β-DIKETONES FROM KETONES AND ACETIC ANHYDRIDE BY BORON TRIFLUORIDE–DIACETIC ACID COMPLEX (BTDA)

Ketone	β Diketones	Registry no.	Bp (mm) or mp, °C	Yield, %	Previous methods, %	
					BF$_3$[a]	Bases[b]
2-Butanone	3-Methyl-2,4-pentanedione	815-57-6	92–93 (68)	48[c]	32	9
2-Pentanone	3-Ethyl-2,4-pentanedione	1540-34-7	85–87 (21)	57[c,d]	31	2
2-Heptanone	3-*n*-Butyl-2,4-pentanedione	1540-36-9	94–96 (9)	74[c]	74–77	<1
Phenylacetone[e]	3-Phenyl-2,4-pentanedione	5910-25-8	56–58	68[d]	41–63	10–23
3-Methyl-2-butanone	3,3-Dimethyl-2,4-pentanedione	3412-58-3	93 (40)	40–47[c,d]	19	
Cyclohexanone	2-Acetylcyclohexanone	874-23-7	115–117 (20)	73[c]	75–86	35
Cyclopentanone	2-Acetylcyclopentanone	1670-46-8	101–103 (24)	80[c]	59–76	
Diethyl ketone	3-Methyl-2,4-hexanedione	4220-52-4	98–100 (30)	81[c]	62	16–45
Dibenzyl ketone	1,3-Diphenyl-2,4-pentanedione	19588-08-0	64–66	72		
Acetophenone	Benzoylacetone	93-91-4	55–57	70	70–83	65–70

[a] See ref 2, pp 131, 133, and 186. [b] See ref 2, pp 136–139. [c] Vpc pure. [d] Obtained in the presence of 5–10 mol % of *p*-toluenesulfonic acid. [e] Purified through its sodium bisulfite addition product.

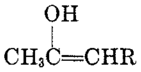
with boron trifluoride gas than by slow saturation[8] or when the boron trifluoride–diacetic acid complex (BTDA) was employed; this was especially true when the two latter procedures were used in the presence of a catalytic amount of *p*-toluenesulfonic acid (see footnote *b*, Table I). Moreover, when the fast saturation procedure was employed with methyl *n*-amyl ketone and acetic anhydride and the reaction mixture worked up after only 15 min, the proportion of methyl derivative was considerably greater (40%) than that (26%) obtained after the usual 2-hr period.

These results are explained by the dual formation of β diketones considered above. Evidently, all of the methyl derivative **12** from each of the three methyl *n*-alkyl ketones listed in Table I was produced by direct C acetylation through the boron trifluoride–enol-type complex **17**, since only the methylene derivative **13** should be expected by the indirect O acetylation of such ketones which are known to undergo proton-catalyzed enolization of only methylene hydrogen to form enols **18** as intermediates.[4] Although some of the methylene derivative **13** may have been produced by direct C acetylation through the boron trifluoride–enol complex **19**, most of **13** probably arose by O acetylation through enols **18** especially in the slow saturation and BTDA procedures.



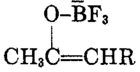
$CH_2{=}\overset{O-\bar{B}F_3}{C}CH_2R$

17



$CH_3\overset{OH}{C}{=}CHR$

18



$CH_3\overset{O-\bar{B}F_3}{C}{=}CHR$

19

Interestingly, to the extent that the methyl derivative **12** was formed from the methyl *n*-alkyl ketones, and this amounted to 14–36% in the fast saturation procedure (see Table I), the presumably less stable boron trifluoride–enol complex **17** was the intermediate. A possible explanation for this is that hydrogen bonding with fluorine initiates some ionization of an α hydrogen of the methyl group (see **7**, Scheme I). Presumably, such hydrogen bonding also initiates some ionization of an α hydrogen of the methylene group to form the more stable complex **19** but the extent of its formation was not evident since the methylene derivative **13** probably arose by both courses of reaction. The above observation that the proportion of methyl derivative **12** (R = *n*-C_4H_9) was greater in the fast saturation procedure after 15 min than after 2 hr may be explained by occurrence of relatively more direct C acetylation during the shorter period before generation of much by-product proton acid, which promoted O acetylation leading to methylene derivative **13** (R = *n*-C_4H_9). Also, some isomerization of intermediate complex **17** to the more stable complex **19** may have occurred during the longer period.

With regard to the influence of the structure of the ketone on the relative proportions of the isomeric β diketone form the methyl methylene ketones, the percentage of the methyl derivative in both the fast and slow saturation procedures increased and that of the methylene derivative decreased as the number of β hydrogens on the methylene side of the ketone was decreased as in the ketone series: methyl ethyl, methyl *n*-alkyl, methyl isobutyl, and methyl neopentyl. The last ketone afforded exclusively the methyl derivative (see Experimental Section). A similar effect of structure of the ketone on the proportions of the methyl and methylene derivatives has previously been observed in O acetylations of methyl methylene ketones with isopropenyl acetate to form ketone enol acetates.[9]

When methyl *n*-amyl ketone was acylated with propionic or butyric anhydride by means of boron trifluoride (slow saturation) in the presence of a catalytic amount of *p*-toluenesulfonic acid, both the methyl and methylene derivatives were produced, the approximate ratio being 25:75. Apparently, the O acylation of the ketone was slower with these higher anhydrides than with acetic anhydride, with which only the methylene derivative was obtained under similar conditions (see Table I).

Improved Method of Synthesis for Certain β Diketones.—Although boron trifluoride gas produces good yields of many β diketones from ketones and acetic anhydride especially when this reagent is first coordinated with ethyl acetate or acetic acid (as monoacid complex),[10] the commercially available boron trifluoride–diacetic acid complex (BTDA) is recommended, since it generally affords equally good or better yields and is more convenient to employ. In Table II are summarized the yields of β diketones obtained using BTDA (in some cases in the presence of *p*-toluene-

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(8) For similar relative proportions of the methyl methylene or methyl methinyl derivatives obtained previously employing slow saturation, and an alkali extraction procedure for separation of the isomers, see ref 7.

(9) E. H. Man, F. C. Frostick, Jr., and C. R. Hauser, *J. Amer. Chem. Soc.*, **74**, 3228 (1952).

(10) R. M. Manyik, F. C. Frostick, Jr., J. J. Sanderson, and C. R. Hauser, *Ibid.*, **75**, 5030 (1953); see also ref 2, pp 129–134.

sulfonic acid) and also the yields realized previously with boron trifluoride or a base.

Table II shows that, with the exception of the acetylation of acetophenone, the acetylations listed in Table II have been realized in poorer yields by means of a basic reagent, with which ethyl acetate is generally employed. Whereas boron trifluoride (as gas or BTDA) produces the methylene or methinyl derivatives of the methyl methylene or methyl methinyl ketones listed in Table II, bases produce mainly the methyl derivatives.[11]

BTDA was found unsatisfactory for effecting the propionylation of methyl *n*-amyl ketone with propionic anhydride because of accompanying anhydride–acetic acid exchange leading to formation of a mixture of the propionyl and acetyl methylene derivatives of the ketone; the relative proportions of these two derivatives and of unchanged ketone were 60:33:7 (by vpc). Propionylation could presumably be realized satisfactorily, however, with a complex of boron trifluoride and propionic acid.

Experimental Section[12]

Isolation of Ketone Enol Acetates. A. From Cyclohexanone.—A stirred mixture of 0.3 mol of cyclohexanone and 0.6 mol of acetic anhydride at 0° was treated, during 15 min, with about 14 mol % of boron trifluoride gas (determined by increase in weight of the reaction flask and contents). After stirring and cooling for 2 hr, the reaction mixture was poured into sodium acetate solution at room temperature, and the resulting mixture was extracted with ether. The combined ethereal extract was washed free of acid with saturated sodium bicarbonate solution, followed by water, and dried (Drierite). The solvent was removed, and the residue was distilled to give 3.1 g (22%) of cyclohexenyl acetate (**2**), bp 74–77° (17 mm) [lit.[4] bp 74–76° (17 mm)].

Anal. Calcd for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.46; H, 8.27.

In another experiment, a mixture of 0.1 mol of cyclohexanone, 0.2 mol of acetic anhydride, and 0.015 mol of boron trifluoride–diacetic acid complex (BTDA)[13] was stirred at 0–10° for 2 hr. The reaction mixture was then treated with water and worked up as described above to give 2.1 g (15%) of **2**, bp 73–76° (17 mm); the vpc retention time of this product was identical with that of an authentic sample of enol acetate **2**.[4]

A mixture of this product **2** (1.4 g, 0.01 mol) and acetic anhydride (0.02 mol) was saturated with boron trifluoride at 0–10°, and the reaction mixture decomposed with hot sodium acetate[2,10] to give 0.75 g (76%) of 2-acetycyclohexanone, bp 94–96° (10 mm) [lit.[9] bp 95–98° (10 mm)]; the vpc retention time of this product was identical with that of an authentic sample.

B. From Methyl Ethyl Ketone.—To a stirred mixture of 0.3 mol of this ketone and 0.6 mol of acetic anhydride at 0–10° was added 10 mol % of boron trifluoride gas as described under A to give 1.1 g (3%) of ketone enol acetate **4a**, bp 117–121° (750 mm) [lit.[14] bp 118–120° (751 mm)].

This product was treated with acetic anhydride and excess boron trifluoride at 0–10°, followed by sodium acetate solution, to give boron difluoride complex **6** of 3-methyl-2,4-pentanedione, mp and mmp 93.5–94.5° (lit.[3] mp 94–94.5°).

C. From Methyl *n*-Amyl Ketone.—A mixture of 0.3 mol of methyl *n*-amyl ketone and 0.6 mol of acetic anhydride was treated with boron trifluoride gas as described under A to give 2.35 g (5%) of enol acetate **4b**, bp 60–64° (10 mm) [lit.[4] bp 75–76° (17 mm)].

This product was treated with acetic anhydride and boron trifluoride, followed by sodium acetate, to afford 3-*n*-butyl-2,4-pentanedione, bp 104–106° (20 mm), which gave the gray copper chelate, mp 184–185° (lit.[7] mp 185–186°).

Isolation of β Diketone Enol Acetates. A. From Cyclohexanone.—A stirred mixture of 0.5 mol of cyclohexanone and 1.0 mol of acetic anhydride at −30 to −20° was saturated, during 40 min, with boron trifluoride gas. After stirring for 80 min longer at the same temperature, the reaction mixture was hydrolyzed with hot sodium acetate solution and worked up. There was isolated, besides recovered cyclohexanone, 16.5 g (16%) of the enol acetate of 2-acetylcyclohexanone (**3**), bp 130–135° (12 mm).

Anal. Calcd for $C_{10}H_{14}O_3$: C, 65.91; H, 7.74. Found: C 66.01; H, 7.80.

In another experiment, 0.25 mol of the ketone and 0.5 mol of the anhydride were used to give 8% of the enol acetate of 2-acetylcyclohexanone (**3**), bp 126–129° (10 mm).

Anal. Calcd for $C_{10}H_{14}O_3$: C, 65.91; H, 7.74. Found: C, 65.82; H, 8.01.

When the reaction was carried out at 0°, none of the β diketone enol acetate **3** was isolated; instead, some 2-acetylcyclohexanone was obtained.

A sample (0.025 mol) of β-diketone enol acetate **3** was added, during 3 min, to stirred boron trifluoride diacetaic acid complex (BTDA)[13] (0.03 mol) cooled in an ice bath. After 30 min, the reaction mixture was warmed to 50–70° and the evolved gas was collected in a trap cooled in a Dry Ice–acetone bath. The liquid in the trap was identified as acetyl fluoride: bp *ca.* 20° (lit.[15] bp 20–21°); ir (gas) 1870 (C=O) [lit.[15] 1869 and 1180 cm^{-1} (CF)]. This product reacted readily with aniline to give acetanilide, mp and mmp 113–115°.

The colored semisolid remaining in the flask was decolorized with activated charcoal and recrystallized from glacial acetic acid to give boron difluoride complex **1** of 2-acetylcyclohexanone, mp and mmp 77–79°, yield about 35%.

B. From Methyl Ethyl Ketone.—A stirred mixture of 0.25 mol of this ketone and 0.5 mol of acetic anhydride at 0–10° was saturated, during 10 min, with boron trifluoride gas. After 1 hr at the same temperature, the reaction mixture was worked up to give 3.8 g (10%) of the enol acetate of 3-methyl-2,4-pentanedione (**5a**), bp 115–117° (30 mm) [lit.[3] bp 115–117° (30 mm)].

This compound (**5a**) was added to excess boron trifluoride–monoacetic acid complex[10] at 0°. After stirring for 2 hr, the reaction mixture was heated on the steam bath until the vapor temperature reached 50°. The material which had collected in a trap cooled in a Dry Ice–acetone bath was redistilled to give acetyl fluoride, bp 22°, in about 50% yield.

C. From Methyl *n*-Amyl Ketone.—A mixture of this ketone (0.2 mol) and acetic anhydride (0.4 mol) at 0–10° was saturated during 10–15 min, with boron trifluoride gas, and the reaction mixture was worked up to give 6.4 g (16%) of the enol acetate of 3-*n*-butyl-2,4-pentanedione (**5b**), bp 114–117° (10 mm).

Anal. Calcd for $C_{11}H_{18}O_3$: C, 66.64; H, 9.15. Found: C, 66.96; H, 8.88.

This product was treated with boron trifluoride, followed by sodium acetate, to give 3-*n*-butyl-2,4-pentanedione, bp 104–106° (20 mm) [lit.[16] bp 102–106° (20 mm)], in 42% yield.

Isolation of Boron Difluoride Complexes of β Diketones from Methylene Ketones. A. From Cyclohexanone.—To a stirred mixture of 0.1 mol of cyclohexanone and 0.2 mol of acetic anhydride at 0° was added 0.2 mol of boron trifluoride–diacetic acid complex.[13] After being allowed to warm to room temperature during 1 hr, the reaction mixture was poured onto 300 ml of cold water. The resulting precipitate was collected, washed with water, and recrystallized from glacial acetic acid to give 8.2 g (70%) of the boron difluoride complex of 2-acetylcyclohexanone (**1**), mp 79–81°.

Anal. Calcd for $C_8H_{11}BF_2O_2$: C, 51.10; H, 5.90; B, 5.75; F, 20.20. Found: C, 51.29; H, 6.21; B, 5.72; F, 20.27.

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(11) See R. Levine, J. A. Conroy, J. T. Adams, and C. R. Hauser, *J. Amer. Chem. Soc.*, **67**, 1510 (1945); also see ref 2, pp 60–88.

(12) Boiling points and melting points are uncorrected. Analyses were by Clark Microanalytic Laboratory, Urbana, Ill., Arlington Laboratories, Fairfax, Va., and Crobaugh Laboratories, Charleston, W. Va. Vpc determinations were made on an F & M Model 500 gas chromatograph using a 15-ft silicone rubber column. Ketones and anhydrides were purified by distillation.

(13) This liquid coordination complex ($BF_3 \cdot 2CH_3COOH$), which contained 36% by weight BF_3, was obtained from Harshaw Chemical Co., Cleveland, Ohio.

(14) B. H. Gwynn and E. F. Degering, *J. Amer. Chem. Soc.*, **64**, 2216 (1942).

(15) J. Overend and J. Scherer, *Spectrochim. Acta*, **16**, 773 (1960).

(16) F. G. Young, F. Frostick, Jr., J. Sanderson, and C. R. Hauser, *J. Amer. Chem. Soc.*, **72**, 3635 (1950).

Similarly, difluoride complex 1 was obtained by treatment of a mixture of cyclohexanone and acetic anhydride with boron trifluoride gas, and the product recrystallized from glacial acetic acid. A sample of the complex was converted into 2-acetylcyclohexanone by means of hot sodium acetate solution.

Also, boron difluoride complex 1 was prepared from 2-acetylcyclohexanone and boron trifluoride gas, and found to be identical with that obtained as described above.

B. From Methyl Ethyl Ketone.—A stirred mixture of 0.25 mol of this ketone and 0.5 mol of acetic anhydride was saturated with boron trifluoride at 0–10°. After 4 hr, the reaction mixture was poured into a solution of 42 g of sodium acetate in 300 ml of water. After cooling in an ice bath for 30 min, the solid was collected and recrystallized from methanol, giving 10.5 g (26%) of the boron difluoride complex of 3-methyl-2,4-pentanedione (6), mp 93.5–94.5° (lit.[3] mp 94–94.5°).

This complex (0.059 mol) was refluxed for 15 min with sodium acetate solution to give 5.0 g (75%) of 3-methyl-2,4-pentanedione, bp 77–79° (30 mm) [lit.[16] bp 75–80° (30 mm)].

Acetylation of Acetophenone. A. Nonformation of Enol Acetate of Ketone.—Attempts to isolate the enol acetate of acetophenone employing acetophenone, acetic anhydride, and either gaseous boron trifluoride or BTDA under the conditions described above for the isolation of enol acetate of cyclohexanone were unsuccessful. In the experiment with BTDA, the material obtained on working up the reaction mixture was shown by vpc to consist of only recovered acetophenone (85%) and benzoylacetone (8%); no third peak in the appropriate region for the enol acetate of acetopheone was observed, indicating that not even a trace of this product was produced.

B. Evidence for Enol-Type Complex 8.—A stirred solution of 6.0 g (0.05 mol) of acetophenone in 40 ml of ethylene chloride at 0–10° was saturated with boron trifluoride gas to produce a white precipitate. After 10 min, 3.0 ml (0.06 mol) of bromine in 10 ml of ethylene chloride was added during 5 min. The brown color was discharged and part of the precipitate was dissolved during the addition of the first few milliliters of the bromine solution. The brownish reaction mixture was refluxed with aqueous sodium acetate (0.1 mol) for 2 hr. After cooling, the resulting mixture was extracted with ether. The ethereal extracts were combined and dried (Drierite), and the solvent was removed. The brownish residue was distilled under vacuum to give 3.0 g (34%) of phenacyl acetate, bp 115–120° (1.5 mm), mp 37–39 and 43–45° after recrystallization from ethanol–petroleum ether (bp 30–60°) (lit.[17] mp 40°). This melting point was not depressed on admixture with authentic phenacyl acetate (mp 44–46°) prepared in 56% yield from phenacyl bromide and sodium acetate. The infrared spectra of the two samples were identical.

A blank experiment carried out with acetophenone and bromine in the absence of boron trifluoride failed to give phenacyl acetate, and 90% of the ketone was recovered.

C. Formation of Boron Trifluoride and Difluoride Complexes of Benzoylacetone.—A solution of 1.0 mol of acetophenone and 2.0 mol of acetic anhydride in 100 ml of ethylene chloride was saturated with boron trifluoride gas at 10° during 2.5 hr. The solid was filtered, washed thoroughly with ether, and dried in air. The product, mp 140–146°, slowly etched glass on standing at room temperature, indicating that it consisted partly of the boron trifluoride complex of benzoylacetone (9). Recrystallization of the product from glacial acetic acid afforded 67.4 g (32%) of the boron difluoride complex of benzoylacetone (10), mp 154–155.5° (lit.[18] mp 154–155°).

Boron trifluoride complex 9 is readily converted into boron difluoride complex 10, especially in the presence of oxygen compounds. When produced from benzoylacetone and boron trifluoride etherate[19] at 0°, crude trifluoride complex 9, mp 136–140°, evolved hydrogen fluoride readily (etched glass) and afforded a difluoride complex 10, mp 154–155°, after recrystallization from glacial acetic acid. When produced in ether at 10–22° or in benzene at 14–20° (but warmed to 35°), the trifluoride complex 9 was converted directly into difluoride complex 10. Even when a solution of 0.3 mol each of benzoylacetone and acetophenone and 0.6 mol of acetic anhydride in 250 ml of ligroin (bp 90–120°) was saturated with boron trifluoride gas below 0°, the solid obtained evidently consisted mainly of difluoride complex 10 with only a little of trifluoride complex 9 since it etched glass very slowly. Recrystallization from glacial acetic acid afforded 10, mp 154–155°.

In an experiment employing BTDA, the pure boron difluoride complex 10, mp 153–155°, was isolated in 39% yield, and converted into benzoylacetone, mp 55–57°, with hot sodium acetate solution.

Relative Proportions of Methyl and Methylene Derivatives from Acetylation of Methyl Methylene Ketones.—In Table I are summarized the relative proportions of isomeric β diketones from acetylation of methyl methylene (or methyl methinyl) ketones obtained under various conditions and determined by vpc. The three procedures employed are indicated below.

A. Fast Saturation Procedure.—A mixture of the ketone (0.1 mol) and acetic anhydride (0.2 mol) was saturated as rapidly as possible (15–20 min) with boron trifluoride gas as described previously.[10] The product was distilled and the distillate analyzed by vpc.[12]

B. Slow Saturation Procedure.—A mixture of the ketone (0.1 mol) and acetic anhydride (0.2 mol) was slowly saturated (during 3–4 hr) with boron trifluoride gas as described previously.[7] The product was distilled and the distillate analyzed by vpc.[12]

Certain of the ketones listed in Table I were also acetylated by this procedure in the presence of 10 mol % or less of *p*-toluenesulfonic acid monohydrate.

Similarly, a mixture of 0.1 mol of methyl neopentyl ketone, 0.2 mol of acetic anhydride, and 0.01 mol of *p*-toluenesulfonic acid monohydrate was stirred for 5–10 min at room temperature, then cooled to 0–10° and saturated slowly with boron trifluoride to give 7.5 g (48%) of 2,2-dimethyl-4,6-heptanedione, bp 97–102° (40 mm) [lit.[9] bp 99° (40 mm)], and copper chelate, mp 117–118° (lit.[9] mp 117–118°). None of the methylene derivative was isolated.

C. Procedure Using BTDA.[13]—To a stirred mixture of 0.1 mol of the ketone and 0.2 mol of acetic anhydride cooled in a water bath at room temperature was added rapidly 0.2 mol of BTDA.[13] Some heat was generated. After stirring at room temperature overnight (about 12 hr), the reddish brown reaction mixture was poured onto a solution of 0.4 mol of sodium acetate in 300 ml of water, and the resulting mixture was refluxed for 1–3 hr. The product was extracted three times with ether and the extracts were combined. The ethereal solution was washed free of acid with saturated sodium bicarbonate solution and dried (Drierite). The solvent was removed and the residue was distilled under vacuum. The distillate was analyzed by vpc.[12]

Improved Method of Synthesis of Acetyl Derivatives of Methylene or Methinyl Ketones.—In Table II are summarized the yields of β diketones obtained from acetylation of methylene or methinyl ketones and acetophenone employing boron trifluoride–diacetic acid complex (BTDA),[13] as described in the preceding section C. These yields were based on products that were pure by vpc.[12] The products were identified by agreement of the boiling point or melting point with reported values and/or by vpc.

Although a reaction period of about 12 hr was generally employed, shorter reaction periods afforded only about 8–13% lower yields in the acetylation of cyclohexanone; thus the yields of 2-acetylcyclohexanone after 5 min, 30 min, and 1 hr were 60, 62, and 65%, respectively. Also, acetylation of phenylacetone to form 3-phenyl-2,4-pentanedione was realized in about 50% yield after 4 hr, compared with the 68% yield after 12 hr. However, acetylation of methyl *n*-amyl ketone during 1 hr produced 3-*n*-butyl-2,4-pentanedione in only 10% yield (see Table II).

Registry No.—Acetic anhydride, 108-24-7; boron trifluoride, 7637-07-2; 1, 19613-66-2; 3, 14768-84-4; 5b, 19588-00-2.

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[17] J. B. Ruther and E. E. Reid, *J. Amer. Chem. Soc.*, **41**, 75 (1919).

[18] G. Morgan and R. Tunstall, *J. Chem. Soc.*, **125**, 1963 (1924).

[19] See H. Meerwein and D. Vossen, *J. Prakt. Chem.*, **141**, 149 (1934).